5.0 Persons and Agencies Consulted

5.1 Federal Agencies

United States Fish and Wildlife Service

National Marine Fisheries Service

United States Army Corps of Engineers

5.2 State Agencies

Oregon State Office of Archaeology and Historic Preservation

Oregon Department of Fish and Wildlife

Oregon Department of Environmental Quality

Oregon Division of State Lands

Oregon Department of Land Conservation and State Lands

Energy Facility Siting Council, Oregon Department of Energy

Oregon Department of Transportation

5.3 Local Agencies

Linn County Planning and Building Department

Marion County Planning and Building Department

Marion County Department of Community Development

5.4 Tribes

Confederated Tribes of Grand Ronde

5.5 Utilities

Portland General Electric

5.6 Landowners

There are approximately 100 landowners on the mailing list.

6.0 References

Applied Archaeological Research. May 22, 2001. Results of a Cultural Resources Survey of the Bonneville Power Administration's Santiam-Bethel Tap Transmission Line Project, Marion County, Oregon. (Applied Archaeological Research Report No. 181) Portland, OR. Prepared for Bonneville Power Administration, Portland, OR.

Bonneville Power Administration. 2000. Transmission system vegetation management program. Final environmental impact statement. DOE/EIS-0285. Portland, OR.

Bracken, T. Dan. June 2001. Santiam-Bethel Transmission Project, *Appendix A, Electrical Effects.*

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deep water habitats of the United States. (FWS/OBS-79/31.) U.S. Fish and Wildlife Service. Washington, DC.

Fennimore, Joe. June 8, 2001. Associate Planner, Marion County Community Development Department. Telephone conversation..

Hopkins, S. Planner. May 1, 2001. Linn County Planning Department, OR. Telephone conversation.

Hunt, W. April 30, 2001. Assistant district fish biologist. Oregon Department of Fish and Wildlife, Corvallis, OR. Telephone conversation.

Jones & Stokes. May 17, 2001. Upgrade to the Bonneville Power Administration Santiam to Bethel, Oregon transmission line. Draft biological assessment. (J&S 0P008.01.) Bellevue, WA. Prepared for Bonneville Power Administration, Portland, OR.

Linn County, Oregon. 2000. Linn County parks. Available: <http://www.co.linn.or.us/>. Accessed May 8, 2001.

______. 2001. Recreational facilities. Available: <http://www.co.linn.or.us/>. Accessed April 20, 2001.

Marion County, Oregon. 2001. Recreational facilities. Available: <http://www.co.marion.or.us>. Accessed April 20, 2001.

Maser, C. 1998. Mammals of the Pacific Northwest: from the coast to the high Cascades. Oregon State University Press. Corvallis, OR.

McMaster, K. State Supervisor, USFWS Oregon State Office, Portland, OR. October 27, 2000 – letter to Leslie Kelleher of Bonneville Power Authority.

Mitsch, W.J., and J.G. Gosselink. 1993. Wetlands. International Thomson Publishing. New York, NY.

ODFW (Oregon Department of Fish and Wildlife). 1993. Oregon wildlife diversity plan. Portland, OR.

ODFW. 1997. Oregon Department of Fish and Wildlife guidelines and criteria for stream-road crossings. Portland, OR.

Oregon Department of Environmental Quality. 1998a. Map of 303(d) listed waterbodies and sub basin priorities. Available: <http://waterquality.deq.state.or.us/WQLData/303dListMap.htm>. Accessed April 26, 2001.

Oregon Department of Environmental Quality. 1998b. Final 1998 303(d) file download page. Available: <http://waterquality.deq.state.or.us/wq/303dlist/Download303d.htm>. Accessed. April 26, 2001.

Oregon Labor Market Information System. 2001. Oregon Employment Department unemployment and poverty statistics. Available: <http://www.olmis.org>. Accessed April 16, 2001.

Oregon Natural Heritage Program. 2001. Natural Heritage database. Portland, OR.

Oregon State University. 1997a. Oregon agriculture census, Linn County, 1997. Available: <http://govinfo.library.orst.edu/cgi-bin/ag-list?01-043.orc>. Accessed May 10, 2001.

______. 1997b. Oregon agriculture census, Linn County, 1997. Available: <http://govinfo.library.orst.edu/cgi-bin/ag-list?28-043.orc>. Accessed May 10, 2001.

______. 1997c. Oregon agriculture census, Marion County, 1997. Available: <http://govinfo.library.orst.edu/cgi-bin/ag-list?01-047.orc>. Accessed May 10, 2001.

______. 1997d. Oregon agriculture census, Marion County, 1997. Available: <http://govinfo.library.orst.edu/cgi-bin/ag-list?28-047.orc>. Accessed May 10, 2001.

Oregon State University, Agricultural Extension. 1999. Oregon State University Extension agricultural statistics, Linn County, last updated April 23, 2001. Available: <http://oregonstate.edu/extension/linn/Agstats1.html>. Accessed May 10, 2001.

Oregon State University, Extension Economic Information Office. 1999. Marion County agricultural commodity sales, 1999 (preliminary), last updated April 18, 2000. Available: <http://www.open.org/~mcboc/agsales.htm>. Accessed May 10, 2001.

Portland State University Population Research Center. 2000. Population, ethnic, gender, and age distribution. Available: <http://www.upa.pdx.edu/CPRC/>. Accessed April 11, 2001.

Salem OnLine. 2000. Salem OnLine. Available: <http://www.salemlodging.com/index.html>. Accessed May 8, 2001.

U.S. Bureau of the Census. 1997. 1997 Model-based income and unemployment estimates. Available: <http://www.census.gov>. Accessed April 10, 2001.

______. 2000. 1999 unemployment rates. Available: <http://www.census.gov>. Accessed April 10, 2001.

U.S. Bureau of Economic Analysis. 1998. Regional accounts data, employment sectors, annual earnings by industry sector, income and unemployment. Available: <http://www.bea.doc.gov/bea/regional/reis/ca05>. Accessed April 18, 2001.

USFWS (U.S. Fish and Wildlife Service). 1986. Recovery plan for the Pacific bald eagle. USDI Fish and Wildlife Service, Portland, OR.

USGS. 2000a. Groundwater atlas of the United States: Idaho, Oregon, and Washington. HA730-H. Available: <http://capp.water.usgs.gov/gwa/ch_h/jpeg/H083.jpeg>. Accessed April 30, 2001.

______. 2000b. 1990 water use. Available: <http://water.usgs.gov>. Accessed April 30, 2001.

Wheeldon, Robert. June 6, 2001. Associate Planner, Linn County Planning and Building Department. Telephone conversation.

7.0 Glossary and Acronyms

Acronyms

A	Ampere
BPA	Bonneville Power Administration
CWA	Clean Water Act
DLC	Donation Land Claim
EFH	Essential Fish Habitat
EMF	Electric and magnetic fields
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency
ESU	Evolutionarily Significant Unit
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
FEMA	Federal Emergency Management Agency
NAS	National Academy of Sciences
NEPA	National Environmental Policy Act
NESC	National Electrical Safety Code
NIEHS	National Institute of Environmental Health Sciences
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NWI	National Wetland Inventory
ODFW	Oregon Department of Fish and Wildlife
PEM	Palustrine emergent
PGE	Portland General Electric
PFO	Palustrine forested
PSS	Palustrine scrub-shrub
RI	Radio Interference
ROW	Right-of-way

SWPP	Stormwater Pollution Prevention
TVI	Television Interference
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Service

Technical Terms

Anadromous	Refers to fish such as salmon that hatch and rear in fresh water, move to the ocean to mature, and then return to fresh water to reproduce.
Alluvium	Material such as sand, silt, or clay that has been deposited on land by running water of streams and rivers.
Arcing	The process of current flowing across a gap, such as fault current flowing across an insulator string that flashed over due to a lightening strike.
Biological Assessment	A document required by the Endangered Species Act, which requires an evaluation of potential effects on listed species and critical habitat prior to implementing a proposed action. A proposed action is defined as any activity authorized, funded or carried out by a federal agency.
Blackouts	The disconnection of the source of electricity from all the electrical loads in a certain geographical area. Brought about by an emergency forced outage or other fault in the generation, transmission or distribution system serving the area.
Capacity	A measure of the ability of the transmission line to carry electricity.
Circuit	A system of conductors through which an electric current is intended to flow.
Conductor	Any metallic material, usually in the form of wire, cable, or bar, suitable for carrying an electrical current.
Corona	The phenomenon whereby the electric field associated with a power line cause ionization (molecular breakdown) of surrounding air, thus creating a high-frequency noise. This noise can be heard as static over an automobile radio when travelling under the power line.
Danger tree	Trees that pose a danger or hazard to the transmission line.
Double-circuit line	To place two separate electrical circuits on the same transmission structures or poles. Each circuit contains three separate conductors or bundles of conductors.

Floodplain	That portion of a river valley adjacent to the stream channel which is covered with water when the stream overflows its banks during flood stage.
Lattice steel	Refers to transmission towers constructed of multiple steel members that are connected together (usually in triangular shapes) to make up a frame.
Load	The amount of electric energy delivered or required at any specific point or points on a system. Load originates primarily at the energy using equipment of consumers, such as heaters, air conditioners, lights and motors. At BPA, load includes delivery to direct service industries (Note: Load is slightly larger than metered energy because of normal transmission and distribution losses in delivery from generator to consumer). Because loads are used to determine resource requirements, forecasts of electricity use are converted to loads.
Median	The middle number in a given sequence of numbers.
Mitigation	Steps taken to remove or lessen the effects predicted for each resource, as potentially caused by the transmission project. They may include reducing the impact, compensating for the impact, or avoiding it entirely. Some measures, such as adjusting the location of the towers to avoid a particular resource, are taken during the study and location process. Others, such as reseeding access roads, and/or avoiding the proliferation of weeds, are taken following project completion.
National Electrical Safety Code (NESC)	Written standards for the design, construction, maintenance and operation of electric supply and communication lines, equipment, and supply station in order to safeguard persons from hazards associated with those activities.
National Environmental Policy Act (NEPA)	A 1969 federal law that required evaluation of the environmental impact of federally funded projects and programs.
Noxious weeds	Plants that are injurious to public health, crops, livestock, land, or other property.
Outage	An event, caused by a disturbance on the electrical system, that requires BPA to remove a piece of equipment or a section of line from service. The disturbance can be either natural or caused by humans.
Overload	When too much current flows through transmission facilities that could cause damage or overheating. In the event of overloading, equipment has safeguards to disconnect it from the flow of electricity.

Palustrine emergent wetland	A shallow freshwater wetland characterized by erect, rotted, herbaceous hydrophytes (water loving plants).
Palustrine forested wetland	A wetland characterized by woody vegetation that is 20 feet or more in height.
Palustrine scrub-shrub wetland	A wetland dominated by woody vegetation less than 20 feet tall. This vegetation includes true shrubs, young trees, and trees and shrubs that are small or stunted because of environmental conditions.
Peak load	The maximum electrical load or the maximum average load during a designated interval such as 15 minutes.
Per capita	Per person
Reliability	The measure of the ability of a power system to provide uninterrupted service, even while that system is under stress.
Right-of-way (ROW)	An easement for a certain purpose over the land of another, such as a strip of land, electric transmission line ditch or pipeline. BPA usually acquires easements for its transmission lines, roads and other facilities such as guys and anchors.
Single-circuit	One electrical circuit consisting of three separate conductors or three bundles of conductors.
Substation	A non-generating electrical power station that serves to transform voltages to higher or lower levels, and that serves as a delivery point to individual customers such as utilities or large industrial plants. The BPA system has more than 400 substations.
Tap	A short transmission line that connects a substation to an existing transmission line.
Transmission grid	An interconnected network of transmission lines and associated equipment for the bulk transfer of electric energy between points of supply and demand. The BPA transmission grid includes some 22,500 circuit kilometers (14,00 circuit miles) of lines connecting more than 400 substations in the Pacific Northwest. The main grid consists of 230-kV, 345-kV, and 500-kV transmission lines.
Transmission line	A high-voltage power line used to carry electric power efficiently over long distances.
Voltage	The driving force that cause a current to flow in an electric circuit. Voltage and volt are often used interchangeably.
Wetlands	An area where the soil experiences anaerobic conditions because of inundation of water during part of any given year. Indicators of a wetland include types of plants, soil characteristics and hydrology.

SANTIAM - BETHEL TRANSMISSION PROJECT

APPENDIX A

ELECTRICAL EFFECTS

June 2001

Prepared by

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for

Bonneville Power Administration

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ELECTRICAL EFFECTS FROM THE PROPOSED SANTIAM - BETHEL TRANSMISSION PROJECT

1.0 Introduction

The Bonneville Power Administration (BPA) is proposing to build a 16.7-mile (mi.) (26.9-kilometer [km]) 230-kilovolt (kV) transmission line from the Santiam Substation near Stayton, Oregon, to a tap point on the existing PGE 230-kV Bethel line near Salem, Oregon. The proposed Santiam - Bethel Transmission Project would replace 16.7 mi. (26.9 km) of the single-circuit Santiam - Chemawa 230-kV line with a double-circuit 230-kV line. The proposed double-circuit line would consist of the new Santiam - Bethel 230-kV line and the rebuilt Santiam - Chemawa 230-kV line. Configurations along the existing line route include the right-of-way with no parallel lines (15.2 mi. or 24.5 km) and the right-of-way parallel to an existing 500-kV line (1.5 mi. or 2.4 km). The purpose of this report is to describe and quantify the electrical effects of the proposed Santiam - Bethel Transmission Project. These include the following:

- the levels of 60-hertz (Hz; cycles per second) electric and magnetic fields (EMF) at 3.28 feet (ft.) or 1 meter (m) above the ground,
- the effects associated with those fields,
- the levels of audible noise produced by the line, and
- electromagnetic interference associated with the line.

Electrical effects occur near all transmission lines, including those already present along the proposed route for the Santiam - Bethel line. Therefore, the levels of these quantities for the proposed line are computed and compared with those from the existing lines along the route.

The voltage on the conductors of transmission lines generates an electric field in the space between the conductors and the ground. The electric field is calculated or measured in units of volts-per-meter (V/m) or kilovolts-per-meter (kV/m) at a height of 3.28 ft. (1 m) above the ground. The current flowing in the conductors of the transmission line generates a magnetic field in the air and earth near the transmission line; current is expressed in units of amperes (A). The magnetic field is expressed in milligauss (mG), and is usually measured or calculated at a height of 3.28 ft. (1 m) above the ground. The electric field at the surface of the conductors causes the phenomenon of corona. Corona is the electrical breakdown or ionization of air in very strong electric fields, and is the source of audible noise, electromagnetic radiation, and visible light.

To quantify EMF levels along the route, the electric and magnetic fields from the proposed and existing lines were calculated using the BPA Corona and Field Effects Program (USDOE, undated). In this program, the calculation of 60-Hz fields uses standard superposition techniques for vector fields from several line sources: in this case, the line sources are transmission-line conductors. (Vector fields have both magnitude and direction: these must be taken into account when combining fields from different sources.) Important input parameters to the computer program are voltage, current, and geometric configuration of the line. The transmission-line conductors are assumed to be straight, parallel to each other, and located above and parallel to an infinite flat ground plane. Although such conditions do not occur under real lines because of conductor sag and variable terrain, the validity and limitations of calculations using these assumptions have been well verified by comparisons with measurements. This approach was used to estimate fields for the proposed Santiam - Bethel line, where minimum clearances were assumed to provide worst-case (highest) estimates for the fields.

Electric fields are calculated using an imaging method. Fields from the conductors and their images in the ground plane are superimposed with the proper magnitude and phase to produce the total field at a selected location.

The total magnetic field is calculated from the vector summation of the fields from currents in all the transmission-line conductors. Balanced currents are assumed for each three-phase circuit; the contribution of induced image currents in the conductive earth is not included. Peak currents and power flow direction for the proposed and existing lines were provided by BPA and are based on the projected winter peak power loads in 2006. In the case of corridors with more than one line, calculations were performed for similar (maximum) current conditions on both lines.

Electric and magnetic fields for the proposed line were calculated at the standard height (3.28 ft. or 1 m) above the ground (IEEE, 1987). Calculations were performed out to 300 ft. (91 m) from the centerline of the existing corridor. The validity and limitations of such calculations have been well verified by measurements. Because maximum voltage, maximum current, and minimum conductor height above-ground are used, ***the calculated values given here represent worst-case conditions:*** i.e., the calculated fields are higher than they would be in practice. Such worst-case conditions would seldom occur.

The corona performance of the proposed line was also predicted using the BPA Corona and Field Effects Program (USDOE, undated). Corona performance is calculated using empirical equations that have been developed over several years from the results of measurements on numerous high-voltage lines (Chartier and Stearns, 1981; Chartier, 1983). The validity of this approach for corona-generated audible noise has been demonstrated through comparisons with measurements on other lines all over the United States (IEEE Committee Report, 1982). The accuracy of this method for predicting corona-generated radio and television interference from transmission lines has also been established (Olsen et al., 1992). Important input parameters to the computer program are voltage, current, conductor size, and geometric configuration of the line.

Corona is a highly variable phenomenon that depends on conditions along a length of line. Predictions of the levels of corona effects are reported in statistical terms to account for this variability. Calculations of audible noise and electromagnetic interference levels were made under conditions of an estimated average operating voltage (235 kV for the proposed line) and with the average line height (43 ft. or 13.1 m). Levels of audible noise, radio interference, and television interference are predicted for both fair and foul weather; however, corona is basically a foul-weather phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Along the route of the proposed Santiam - Bethel transmission line, such conditions are expected to occur about 22% of the time during a year, based on hourly records for the Salem airport from 1996 to 1999. Corona activity also increases with altitude. For purposes of evaluating corona effects from the proposed line, an altitude of 500 ft. (152 m) was assumed.

2.0 Physical Description

2.1 Proposed Line

The proposed double-circuit line would consist of two three-phase circuits, the new Santiam - Bethel 230-kV line and the rebuilt Santiam - Chemawa 230-kV line. Both circuits would have maximum phase-to-phase voltages of 242 kV. The average voltage of the lines would be 235 kV. The maximum electrical current on the lines would be 755 and 644 amperes per phase for the Santiam - Bethel and Santiam - Chemawa lines, respectively. The estimated currents are based on the BPA projected normal winter peak load in 2006. The load factor for these loads is 0.60 (average load = peak load x load factor). BPA provided the physical and operating characteristics of the proposed and existing lines.

The physical dimensions and electrical characteristics for the configuration of the proposed line are shown in Figure 1, and summarized in Table 1. Each phase of the proposed and rebuilt 230-kV lines will have a single 1.600-inch (in.) (4.1 centimeter [cm]) diameter steel-reinforced aluminum conductor (ACSR). Voltage and current waves are displaced by 120° in time (one-third of a cycle) on each electrical phase. The horizontal phase spacing between the upper and lower conductor positions of the two circuits would be 24.5 ft. (7.5 m); the horizontal spacing between the middle conductor positions would be 40.5 ft. (12.3 m). The vertical spacing between the conductor positions would be 18 ft. (5.5 m). Minimum conductor-to-ground clearance would be 31 ft. (9.5 m) at a conductor temperature of 122°F (50°C), which represents maximum operating conditions and high ambient air temperatures; clearances above ground would be greater under normal operating temperatures. The average clearance above ground along a span will be approximately 43 ft. (13.1 m); this value was used for corona calculations. At road crossings, the ground clearance would be at least 39 ft. (11.9 m). The 31-ft. (9.5-m) minimum clearance provided by BPA is greater than the minimum distance of the conductors above ground required to meet the National Electric Safety Code (NESC) (IEEE, 1990). The final design of the proposed line could entail larger clearances. The right-of-way width for the proposed line is 125 ft. (38 m).

2.2 Existing Lines

The proposed double-circuit 230-kV line would replace a section of the existing Santiam - Chemawa 230-kV line along the entire route. There are two possible configurations along the existing Santiam - Chemawa line route: either no parallel line or parallel to the existing BPA Marion - Santiam No. 1 and No. 2 double-circuit 500-kV line (Table 2).

BPA provided information on currents for the existing Santiam - Chemawa line and for the Marion - Santiam No.1 500-kV line. The Marion - Santiam No. 2 line is not energized. The physical and electrical characteristics of the corridor configurations that were analyzed are given in Table 1; cross-sections of the corridors are shown in Figure 1.

3.0 Electric Field

3.1 Basic Concepts

An electric field is said to exist in a region of space if an electrical charge, at rest in that space, experiences a force of electrical origin (i.e., electric fields cause free charges to move). Electric field is a vector quantity: that is, it has both magnitude and direction. The direction corresponds to the direction that a positive charge would move in the field. Sources of electric fields are unbalanced electrical charges (positive or negative) and time-varying magnetic fields. Transmission lines, distribution lines, house wiring, and appliances generate electric fields in their vicinity because of unbalanced electrical charge on energized conductors. The unbalanced charge is associated with the voltage on the energized system. On the power system in North America, the voltage and charge on the energized conductors are cyclic (plus to minus to plus) at a rate of 60 times per second. This changing voltage results in electric fields near sources that are also time-varying at a frequency of 60 hertz (Hz; a frequency unit equivalent to cycles per second).

As noted earlier, electric fields are expressed in units of volts per meter (V/m) or kilovolts (thousands of volts) per meter (kV/m). Electric- and magnetic-field magnitudes in this report are expressed in root-mean-square (rms) units. For sinusoidal waves, the rms amplitude is given as the peak amplitude divided by the square root of two.

The spatial uniformity of an electric field depends on the source of the field and the distance from that source. On the ground, under a transmission line, the electric field is nearly constant in magnitude and direction over distances of several feet (1 meter). However, close to transmission- or distribution-line conductors, the field decreases rapidly with distance from the conductors. Similarly, near small sources such as appliances, the field is not uniform and falls off even more rapidly with distance from the device. If an energized conductor (source) is inside a grounded conducting enclosure, then the electric field outside the enclosure is zero, and the source is said to be shielded.

Electric fields interact with the charges in all matter, including living systems. When a conducting object, such as a vehicle or person, is located in a time-varying electric field near a transmission line, the external electric field exerts forces on the charges in the object, and electric fields and currents are induced in the object. If the object is grounded, then the total current induced in the body (the "short-circuit current") flows to earth. The distribution of the currents within, say, the human body, depends on the electrical conductivities of various parts of the body: for example, muscle and blood have higher conductivity than bone and would therefore experience higher currents.

At the boundary surface between air and the conducting object, the field in the air and perpendicular to the conductor surface is much, much larger than the field in the conductor itself. For example, the average surface field on a human standing in a 10 kV/m field is 27 kV/m; the internal fields in the body are much smaller: approximately 0.008 V/m in the torso and 0.45 V/m in the ankles.

3.2 Transmission-line Electric Fields

The electric field created by a high-voltage transmission line extends from the energized conductors to other conducting objects such as the ground, towers, vegetation, buildings, vehicles, and people. The calculated strength of the electric field at a height of 3.28 ft. (1 m) above an unvegetated, flat earth is frequently used to describe the electric field under straight parallel transmission lines. The most important transmission-line parameters that determine the electric field at a 1-m height are conductor height above ground and line voltage.

Calculations of electric fields from transmission lines are performed with computer programs based on well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values under these conditions represent an ideal situation. When practical conditions approach this ideal model, measurements and calculations agree. Often, however, conditions are far from ideal because of variable terrain and vegetation. In these cases, fields are calculated for ideal conditions, with the lowest conductor clearances to provide upper bounds on the electric field under the transmission lines. With the use of more complex models or empirical results, it is also possible to account accurately for variations in conductor height, topography, and changes in line direction. Because the fields from different sources add vectorially, it is possible to compute the fields from several different lines if the electrical and geometrical properties of the lines are known. However, in general, electric fields near transmission lines with vegetation below are highly complex and cannot be calculated. Measured fields in such situations are highly variable.

For evaluation of EMF from transmission lines, the fields must be calculated for a specific line condition. The NESC states the condition for evaluating electric-field-induced short-circuit current for lines with voltage above 98 kV, line-to-ground, as follows: conductors are at a minimum clearance from ground corresponding to a conductor temperature of 120°F (49°C), and at a maximum voltage (IEEE, 1990). BPA has supplied the needed information for calculating electric and magnetic fields from the proposed transmission lines: the maximum operating voltage, the estimated peak current in 2006, and the minimum conductor clearances.

There are standard techniques for measuring transmission-line electric fields (IEEE, 1987). Provided that the conditions at a measurement site closely approximate those of the ideal situation assumed for calculations, measurements of electric fields agree well with the calculated values. If the ideal conditions are not approximated, the measured field can differ substantially from calculated values. Usually the actual electric field at ground level is reduced from the calculated values by various common objects that act as shields.

Maximum or peak field values occur over a small area at midspan, where conductors are closest to the ground. As the location of an electric-field profile approaches a tower, the conductor clearance increases, and the peak field decreases. A grounded tower will reduce the electric field considerably by shielding. For the parallel-line configuration considered here, minimum conductor clearances were assumed to occur along the same lateral profile for both lines. This condition will not necessarily occur in practice, because the towers for the parallel lines may be offset or located at different elevations. The assumption of simultaneous minimum clearance results in peak fields that may be larger than what occurs in practice.

For traditional transmission lines, such as the proposed line, where the right-of-way extends laterally well beyond the conductors, electric fields at the edge of the right-of-way are not as sensitive as the peak field to conductor height. Computed values at the edge of the right-of-way for any line height are fairly representative of what can be expected all along the transmission-line corridor. However, the presence of vegetation on and at the edge of the right-of-way will reduce actual electric-field levels below calculated values.

3.3 Calculated Values of Electric Fields

Table 3 shows the calculated values of electric field at 3.28 ft. (1 m) above ground for the proposed Santiam - Bethel 230-kV transmission-line configurations. The peak value on the right-of-way and the value at the edge of the right-of-way are given for the two proposed corridor configurations and for minimum and average conductor clearances. Figure 2a shows lateral profiles for the electric field from the proposed and existing lines for the minimum conductor heights. Figure 2b shows calculated fields for the proposed and existing lines in the configuration with a parallel 500-kV line.

The calculated peak electric field expected on the right-of-way of the proposed line is 2.5 kV/m when there are no parallel lines. As shown in Figure 2a, the peak values would be present only at locations directly under the line, near mid-span, where the conductors are at the minimum clearance. The conditions of minimum conductor clearance at maximum current and maximum voltage occur very infrequently. The calculated peak levels are rarely reached under real-life conditions, because the actual line height is generally above the minimum value used in the computer model, because the actual voltage is below the maximum value used in the model, and because vegetation within and near the edge of the right-of-way tends to shield the field at ground level. Maximum electric field under the existing parallel 500-kV is 8.1 kV/m.

The largest values expected at the edge of the right-of-way nearest the proposed line would be 0.4 kV/m. For the parallel configuration, the field at the edge of the right-of-way nearest the 500-kV line would be 0.3 kV/m. The largest electric fields at the edges of the existing rights-of-way are 1.3 and 2.6 kV/m for the 230- and 500-kV lines, respectively.

3.4 Environmental Electric Fields

The electric fields associated with the Santiam - Bethel line can be compared with those found in other environments. Sources of 60-Hz electric (and magnetic) fields exist everywhere electricity is used; levels of these fields in the modern environment vary over a wide range. Electric-field levels associated with the use of electrical energy are orders of magnitude greater than the naturally occurring 60-Hz fields of about 0.0001 V/m, which stem from atmospheric and extraterrestrial sources.

Electric fields in outdoor, publicly accessible places range from less than 1 V/m to 12 kV/m; the large fields exist close to high-voltage transmission lines of 500 kV or higher. In remote areas without electrical service, 60-Hz field levels can be much lower than 1 V/m. Electric fields in home and work environments generally are not spatially uniform like those of transmission lines; therefore, care must be taken when making comparisons between fields from different sources such as appliances and electric lines. In addition, fields from all sources can be strongly modified by the presence of conducting objects. However, it is helpful to know the levels of electric fields generated in domestic and office environments in order to compare commonly experienced field levels with those near transmission lines.

Numerous measurements of residential electric fields have been reported for various parts of the United States, Canada, and Europe. Although there have been no large studies of residential electric fields, sufficient data are available to indicate field levels and characteristics. Measurements of domestic 60-Hz electric fields indicate that levels are highly variable and source-dependent. Electric-field levels are not easily predicted because walls and other objects act as shields, because conducting objects perturb the field, and because homes contain numerous localized sources. Internal sources (wiring, fixtures, and appliances) seem to predominate in producing electric fields inside houses. Average measured electric fields in residences are generally in the range of 5 to 20 V/m. In a large occupational exposure monitoring project that included electric-field measurements at homes, average exposures for all groups away from work were generally less than 10 V/m (Bracken, 1990).

Electric fields from household appliances are localized and decrease rapidly with distance from the source. Local electric fields measured at 1 ft. (0.3 m) from small household appliances are typically in the range of 30 to 60 V/m. Stopps and Janischewskyj (1979) reported electric-field measurements near 20 different appliances; at a 1-ft. (0.3-m) distance, fields ranged from 1 to 150 V/m, with a mean of 33 V/m. In another survey, reported by Deno and Zaffanella (1982), field measurements at a 1-ft. (0.3-m) distance from common domestic and workshop sources were found to range from 3 to 70 V/m. The localized fields from appliances are not uniform, and care should be taken in comparing them with transmission-line fields.

Electric blankets can generate higher localized electric fields. Sheppard and Eisenbud (1977) reported fields of 250 V/m at a distance of approximately 1 ft. (0.3 m). Florig et al. (1987) carried out extensive empirical and theoretical analysis of electric-field exposure from electric blankets and presented results in terms of uniform equivalent fields such as those near transmission lines. Depending on what parameter was chosen to represent intensity of exposure and the grounding status of the subject, the equivalent vertical 60-Hz electric-field exposure ranged from 20 to over 3500 V/m. The largest equivalent field corresponds to the measured field on the chest with the blanket-user grounded. The average field on the chest of an ungrounded blanket-user yields an equivalent vertical field of 960 V/m. As manufacturers have become aware of the controversy surrounding EMF exposures, electric blankets have been redesigned to reduce magnetic fields. However, electric fields from these “low field” blankets are still comparable with those from older designs (Bassen et al., 1991).

Generally, people in occupations not directly related to high-voltage equipment are exposed to electric fields comparable with those of residential exposures. For example, the average electric field measured in 14 commercial and retail locations in rural Wisconsin and Michigan was 4.8 V/m (ITT Research Institute, 1984). Median electric field was about 3.4 V/m. These values are about one-third the values in residences reported in the same study. Power-frequency electric fields near video display terminals (VTDs) are about 10 V/m, similar to those of other appliances (Harvey, 1983). Electric-field levels in public buildings such as shops, offices, and malls appear to be comparable with levels in residences.

In a survey of 1,882 volunteers from utilities, electric-field exposures were measured for 2,082 work days and 657 non-work days (Bracken, 1990). Electric-field exposures for occupations other than those directly related to high-voltage equipment were equivalent to those for non-work exposure.

Thus, except for the relatively few occupations where high-voltage sources are prevalent, electric fields encountered in the workplace are probably similar to those of residential exposures. Even in electric-utility occupations where high field sources are present, exposures to high fields are limited on average to minutes per day.

Electric fields found in publicly accessible areas near high-voltage transmission lines can typically range up to 3 kV/m for 230-kV lines, to 10 kV/m for 500-kV lines, and to 12 kV/m for 765-kV lines. Although these peak levels are considerably higher than the levels found in other public areas, they are present only in limited areas on rights-of-way.

The calculated electric fields for the proposed Santiam - Bethel 230-kV transmission line are consistent with the levels reported for other 230-kV transmission lines in Oregon and elsewhere. The electric fields on and at the edge of the right-of-way from the proposed line will be less than those from the Santiam - Chemawa 230-kV line that would be replaced. Electric fields from the existing 500-kV line will remain the same and be larger than those from the proposed or existing 230-kV lines. The calculated electric fields on the right-of-way of the proposed transmission line would be much higher than levels normally encountered in residences and offices.

4.0 Magnetic Field

4.1 Basic Concepts

Magnetic fields can be characterized by the force they exert on a moving charge or on an electrical current. As with the electric field, the magnetic field is a vector quantity characterized by both magnitude and direction. Electrical currents generate magnetic fields. In the case of transmission lines, distribution lines, house wiring, and appliances, the 60-Hz electric current flowing in the conductors generates a time-varying, 60-Hz magnetic field in the vicinity of these sources. The strength of a magnetic field is measured in terms of magnetic lines of force per unit area, or magnetic flux density. The term “magnetic field,” as used here, is synonymous with magnetic flux density and is expressed in units of Gauss (G) or milligauss (mG).

The uniformity of a magnetic field depends on the nature and proximity of the source, just as the uniformity of an electric field does. Transmission-line-generated magnetic fields are quite uniform over horizontal and vertical distances of several feet near the ground. However, for small sources such as appliances, the magnetic field decreases rapidly over distances comparable with the size of the device.

The interaction of a time-varying magnetic field with conducting objects results in induced electric field and currents in the object. A changing magnetic field through an area generates a voltage around any conducting loop enclosing the area (Faraday's law). This is the physical basis for the operation of an electrical transformer. For a time-varying sinusoidal magnetic field, the magnitude of the induced voltage around the loop is proportional to the area of the loop, the frequency of the field, and the magnitude of the field. The induced voltage around the loop results in an induced electric field and current flow in the loop material. The induced current that flows in the loop depends on the conductivity of the loop.

4.2 Transmission-line Magnetic Fields

The magnetic field generated by currents on transmission-line conductors extends from the conductors through the air and into the ground. The magnitude of the field at a height of 3.28 ft. (1 m) is frequently used to describe the magnetic field under transmission lines. Because the magnetic field is not affected by non-ferrous materials, the field is not influenced by normal objects on the ground under the line. The direction of the maximum field varies with location. (The electric field, by contrast, is essentially vertical near the ground.) The most important transmission-line parameters that determine the magnetic field at 3.28 ft. (1 m) height are conductor height above ground and magnitude of the currents flowing in the conductors. As distance from the transmission-line conductors increases, the magnetic field decreases.

Calculations of magnetic fields from transmission lines are performed using well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values usually represent the ideal straight parallel-conductor configuration. For simplicity, a flat earth is usually assumed. Balanced currents (currents of the same magnitude for each phase) are also assumed. This is usually valid for transmission lines, where loads on all three phases are maintained in balance during operation. Induced image currents in the earth are usually ignored for calculations of magnetic field under or near the right-of-way. The resulting error is negligible. Only at distances greater than 300 ft. (91 m) from a line do such contributions become significant (Deno and Zaffanella, 1982). The clearance for magnetic-field calculations for the proposed line was the same as that used for electric-field evaluations.

Standard techniques for measuring magnetic fields near transmission lines are described in ANSI IEEE Standard No. 644-1987 (1987). Measured magnetic fields agree well with calculated values, provided the currents and line heights that go into the calculation correspond to the actual values for the line. To realize such agreement, it is necessary to get accurate current readings during field measurements (because currents on transmission lines can vary considerably over short periods of time) and also to account for all field sources in the vicinity of the measurements.

As with electric fields, the maximum or peak magnetic fields occur in areas near the centerline and at midspan where the conductors are the lowest. The magnetic field at the edge of the right-of-way is not very dependent on line height. If more than one line is present, the peak field will depend on the relative electrical phasing of the conductors and the direction of power flow. Phasing information was available for the parallel 500-kV line. Phasing of the proposed line was selected to minimize magnetic field at the edge of the right-of-way.

4.3 Calculated Values for Magnetic Fields

Table 4 gives the calculated values of the magnetic field at 3.28 ft. (1 m) height for the proposed 230-kV transmission-line corridor. Field values on the right-of-way and at the edge of the right-of-way are given for projected maximum currents during winter peak load in 2006, for minimum and average conductor clearances. The maximum currents are 755 A on each of the three phases of the proposed Santiam - Bethel 230-kV line and 644 A on the rebuilt Santiam - Chemawa 230-kV line. Figure 3 shows lateral profiles of maximum magnetic field under this current condition for the two possible corridors of the proposed 230-kV transmission line. The actual magnetic-field levels would vary, as currents on the lines change daily and seasonally and as ambient temperature changes. Average currents over the year would be about 60% of the maximum values. The levels shown in the figures represent the highest magnetic fields expected for the proposed Santiam - Bethel/Santiam - Chemawa 230-kV line. Average fields over a year would be considerably reduced from the peak values, as a result of increased clearances above the minimum value and reduced currents from the maximum value.

The maximum calculated 60-Hz magnetic field expected at 3.28 ft. (1 m) above ground for the proposed line is 87 mG for the proposed line alone and 94 mG when the line parallels the 500-kV line. This field is calculated for the maximum current of 755 A, with the conductors at a height of 31 ft. (9.5 m). The maximum field would decrease for increased conductor clearance. For an average conductor height over a span of 43 ft. (13.1 m), the maximum field would be 50 mG and 58 mG for the proposed line alone and parallel to the 500-kV line, respectively.

At the edge of the right-of-way of the proposed line, the calculated magnetic field for maximum current load conditions is 26 mG. When the line is located parallel to the existing 500-kV line, the field at the edge of the right-of-way adjacent to the proposed line would be 29 mG.

The magnetic field falls off rapidly as distance from the line increases. At a distance of 200 ft. (61 m) from the centerline of the proposed line, the field would be 4 mG for maximum current conditions. The calculated magnetic field for maximum current would be less than 10 mG at about 120 ft. (37 m) from the centerline.

The calculated fields for the two corridors with existing transmission lines are given in Table 4. For the existing lines, the peak magnetic fields on the rights-of-way are 218 mG and 108 mG, for the 230- and 500-kV lines, respectively. Fields at the edges of the existing rights-of-way are 78 mG and 50 mG for the 230- and 500-kV lines, respectively. Addition of the proposed line will not significantly change the magnetic fields under, or at the edge of, the right-of-way of the existing 500-kV line.

4.4 Environmental Magnetic Fields

Transmission lines are not the only source of magnetic fields; as with 60-Hz electric fields, 60-Hz magnetic fields are present throughout the environment of a society that relies on electricity as a principal energy source. The magnetic fields associated with the proposed Santiam - Bethel 230-kV line can be compared with fields from other sources. The range of 60-Hz magnetic-field exposures in publicly accessible locations such as open spaces, transmission-line rights-of-way, streets, pedestrian walkways, parks, shopping malls, parking lots, shops, hotels, public transportation, and so on range from less than 0.1 mG to about 1 G, with the highest values occurring near small appliances with electric motors. In occupational settings in electric utilities, where high currents are present, magnetic-field exposures for workers can be above 1 G. At 60 Hz, the magnitude of the natural magnetic field is approximately 0.0005 mG.

Several investigations of residential fields have been conducted. In a large study to identify and quantify significant sources of 60-Hz magnetic fields in residences, measurements were made in 996 houses, randomly selected throughout the country (Zaffanella, 1993). The most common sources of residential fields were power lines, the grounding system of residences, and appliances. Field levels were characterized by both point-in-time (spot) measurements and 24-hour measurements. Spot measurements averaged over all rooms in a house exceeded 0.6 mG in 50% of the houses and 2.9 mG in 5% of houses. Power lines generally produced the largest average fields in a house over a 24-hour period. On the other hand, grounding system currents proved to be a more significant source of the highest fields in a house. Appliances were found to produce the highest local fields; however, fields fell off rapidly with increased distance. For example, the median field near microwave ovens was 36.9 mG at a distance of 10.5 in. (0.27 m) and 2.1 mG at 46 in. (1.17 m). Across the entire sample of 996 houses, higher magnetic fields were found in, among others, urban areas (vs. rural); multi-unit dwellings (vs. single-family); old houses (vs. new); and houses with grounding to a municipal water system.

In an extensive measurement project to characterize the magnetic-field exposure of the general population, over 1000 randomly selected persons in the United States wore a personal exposure meter for 24 hours and recorded their location in a simple diary (Zaffanella and Kalton, 1998). Based on the measurements of 853 persons, the estimated 24-hour average exposure for the general population is 1.24 mG and the estimated median exposure is 0.88 mG. The average field “at home, not in bed” is 1.27 mG and “at home, in bed” is 1.11 mG. Average personal exposures were found to be largest “at work” (mean of 1.79 mG and median of 1.01 mG) and lowest “at home, in bed” (mean of 1.11 mG and median of 0.49 mG). Average fields in school were also low (mean of 0.88 mG and median of 0.69 mG). Factors associated with higher exposures at home were smaller residences, duplexes and apartments, metallic rather than plastic water pipes, and nearby overhead distribution lines.

As noted above, magnetic fields from appliances are localized and decrease rapidly with distance from the source. Localized 60-Hz magnetic fields have been measured near about 100 household appliances such as ranges, refrigerators, electric drills, food mixers, and shavers (Gauger, 1985). At a distance of 1 ft. (0.3 m), the maximum magnetic field ranged from 0.3 to 270 mG, with 95% of the measurements below 100 mG. Ninety-five percent of the levels at a distance of 4.9 ft. (1.5 m) were less than 1 mG. Devices that use light-weight, high-torque motors with little magnetic shielding exhibited the largest fields. These included vacuum cleaners and small hand-held appliances and tools. Microwave ovens with large power transformers also exhibited relatively large fields. Electric blankets have been a much-studied source of magnetic-field exposure because of the length of time they are used and because of the close proximity to the body. Florig and Hoburg (1988) estimated that the average magnetic field in a person using an electric blanket was 15 mG, and that the maximum field could be 100 mG. New "low-field" blankets have magnetic fields at least 10 times lower than those from conventional blankets (Bassen et al., 1991).

In a domestic magnetic-field survey, Silva et al. (1989) measured fields near different appliances at locations typifying normal use (e.g., sitting at a typewriter or standing at a stove). Specific appliances with relatively large fields included can openers (n = 9), with typical fields ranging from 30 to 225 mG and a maximum value up to 2.7 G; shavers (n = 4), with typical fields from 50 to 300 mG and maximum fields up to 6.9 G; and electric drills (n = 2), with typical fields from 56 to 190 mG and maximum fields up to 1.5 G. The fields from such appliances fall off very rapidly with distance and are only present for short periods. Thus, although instantaneous magnetic-field levels close to small hand-held appliances can be quite large, they do not contribute to average area levels in residences.

Although studies of residential magnetic fields have not all considered the same independent parameters, the following consistent characterization of residential magnetic fields emerges from the data:

(1) External sources play a large role in determining residential magnetic-field levels. Transmission lines, when nearby, are an important external source. Unbalanced ground currents on neutral conductors and other conductors, such as water pipes in and near a house, can represent a significant source of magnetic field. Distribution lines per se, unless they are quite close to a residence, do not appear to be a traditional distance-dependent source.

(2) Homes with overhead electrical service appear to have higher average fields than those with underground service.

(3) Appliances represent a localized source of magnetic fields that can be much higher than average or area fields. However, fields from appliances approach area levels at distances greater than 3 ft. (1 m) from the device.

Although important variables in determining residential magnetic fields have been identified, quantification and modeling of their influence on fields at specific locations is not yet possible. However, a general characterization of residential magnetic-field level is possible: average levels in the United States are in the range of 0.5 to 1.0 mG, with the average field in a small number of homes exceeding this range by as much as a factor of 10 or more. Average personal exposure levels are slightly higher, possibly due to use of appliances and varying distances to other sources. Maximum fields can be much higher.

Magnetic fields in commercial and retail locations are comparable with those in residences. As with appliances, certain equipment or machines can be a local source of higher magnetic fields. Utility workers who work close to transformers, generators, cables, transmission lines, and distribution systems clearly experience high-level fields. Other sources of fields in the workplace include motors, welding machines, computers, and video display terminals (VDTs). In publicly accessible indoor areas, such as offices and stores, field levels are generally comparable with residential levels, unless a high-current source is nearby.

Because high-current sources of magnetic field are more prevalent than high-voltage sources, occupational environments with relatively high magnetic fields encompass a more diverse set of occupations than do those with high electric fields. For example, in occupational magnetic-field measurements reported by Bowman et al. (1988), the geometric mean field from 105 measurements of magnetic field in "electrical worker" job locations was 5.0 mG. "Electrical worker" environments showed the following elevated magnetic-field levels (geometric mean greater than 20 mG): industrial power supplies, alternating current (ac) welding machines, and sputtering systems for electronic assembly. For secretaries in the same study, the geometric mean field was 3.1 mG for those using VDTs (n = 6) and 1.1 mG for those not using VDTs (n = 3).

Measurements of personal exposure to magnetic fields were made for 1,882 volunteer utility workers for a total of 4,411 workdays (Bracken, 1990). Median workday mean exposures ranged from 0.5 mG for clerical workers without computers to 7.2 mG for substation operators. Occupations not specifically associated with transmission and distribution facilities had median workday exposures less than 1.5 mG, while those associated with such facilities had median exposures above 2.3 mG. Magnetic-field exposures measured in homes during this study were comparable with those recorded in offices.

Magnetic fields in publicly accessible outdoor areas seem to be, as expected, directly related to proximity to electric-power transmission and distribution facilities. Near such facilities, magnetic fields are generally higher than indoors (residential). Higher-voltage facilities tend to have higher fields. Typical maximum magnetic fields in publicly accessible areas near transmission facilities can range from less than a few milligauss up to 300 mG or more, near heavily loaded lines operated at 230 to 765 kV. The levels depend on the line load, conductor height, and location on the right-of-way. Because magnetic fields near high-voltage transmission lines depend on the current in the line, they can vary daily and seasonally. To characterize fields from the distribution system, Heroux (1987) measured 60-Hz magnetic fields with a mobile platform along 140 mi. (223 km) of roads in Montreal. The median field level averaged over nine different routes was 1.6 mG, with 90% of the measurements less than about 5.1 mG. Spot measurements indicated that typical fields directly above underground distribution systems were 5 to 19 mG. Beneath overhead distribution lines, typical fields were 1.5 to 5 mG on the primary side of the transformer, and 4 to 10 mG on the secondary side. Near ground-based transformers used in residential areas, fields were 80 to 1000 mG at the surface and 10 to 100 mG at a distance of 1 ft. (0.3 m).

The magnetic fields from the proposed 230-kV transmission line would be less than those from the existing 230-kV line that is being replaced. The fields from the proposed line would be comparable to or less than those from existing 230-kV lines in Oregon and elsewhere. On and near the right-of-way of the proposed line, magnetic fields would be well above average residential levels. However, the fields from the line would decrease rapidly and approach common ambient levels at distances greater than a few hundred feet from the line. Furthermore, the fields at the edge of the right-of-way would not be above those encountered during normal activities near common sources such as hand-held appliances.

5.0 Electric and Magnetic Field (EMF) Effects

Possible effects associated with the interaction of EMF from transmission lines with people on and near a right-of-way fall into two categories: short-term effects that can be perceived and may represent a nuisance, and possible long-term health effects. Only short-term effects are discussed here. The issue of whether there are long-term health effects associated with transmission-line fields is controversial. In recent years, considerable research on possible biological effects of EMF has been conducted. A review of these studies and their implications for health-related effects is provided in a separate technical report for the environmental assessment for the proposed Santiam - Bethel 230-kV transmission line.

5.1 Electric Fields: Short-term Effects

Short-term effects from transmission-line electric fields are associated with perception of induced currents and voltages or perception of the field. Induced current or spark discharge shocks can be experienced under certain conditions when a person contacts objects in an electric field. Such effects occur in the fields associated with transmission lines that have voltages of 230-kV or higher. These effects could occur infrequently under the proposed Santiam - Bethel 230-kV line. The higher electric fields under the existing 500-kV Marion-Santiam line are much more likely to result in such effects.

Steady-state currents are those that flow continuously after a person contacts an object and provides a path to ground for the induced current. The amplitude of the steady-state current depends on the induced current to the object in question and on the grounding path. The magnitude of the induced current to vehicles and objects under the proposed line will depend on the electric-field strength and the size and shape of the object. When an object is electrically grounded, the voltage on the object is reduced to zero, and it is not a source of current or voltage shocks. If the object is poorly grounded or not grounded at all, then it acquires some voltage relative to earth and is a possible source of current or voltage shocks.

The responses of persons to steady-state current shocks have been extensively studied, and levels of response documented (Keesey and Letcher, 1969; IEEE, 1978). Primary shocks are those that can result in direct physiological harm. Such shocks will not be possible from induced currents under the existing or proposed lines, because clearances above ground required by the NESC preclude such shocks from large vehicles and grounding practices eliminate large stationary objects as sources of such shocks.

Secondary shocks are defined as those that could cause an involuntary and potentially harmful movement, but no direct physiological harm. Secondary shocks could occur under the proposed 230-kV line when making contact with ungrounded conducting objects such as vehicles or equipment. However, such occurrences are anticipated to be very infrequent. Shocks, when they occur under the 230-kV line, are most likely to be below the nuisance level. Induced currents are extremely unlikely to be perceived off the right-of-way of the proposed line.

Induced currents are always present in electric fields under transmission lines and will be present near the proposed line. However, during initial construction, BPA routinely grounds metal objects that are located on or near the right-of-way. The grounding eliminates these objects as sources of induced current and voltage shocks. Multiple grounding points are used to provide redundant paths for induced current flow. After construction, BPA would respond to any complaints and install or repair grounding to mitigate nuisance shocks.

Unlike fences or buildings, mobile objects such as vehicles and farm machinery cannot be grounded permanently. Limiting the possibility of induced currents from such objects to persons is accomplished in several ways. First, required clearances for above-ground conductors tend to limit field strengths to levels that do not represent a hazard or nuisance. The NESC (IEEE, 1990) requires that, for lines with voltage exceeding 98 kV line-to-ground (170 kV line-to-line), sufficient conductor clearance be maintained to limit the induced short-circuit current in the largest anticipated vehicle under the line to 5 milliamperes (mA) or less. This can be accomplished by limiting access or by increasing conductor clearances in areas where large vehicles could be present. BPA and other utilities design and operate lines to be in compliance with the NESC.

For the proposed line, conductor clearances (50°C conductor temperature) would be increased to at least 39 ft. (11.9 m) over road crossings along the route, resulting in a maximum field of 1.7 kV/m or less at the 3.28 ft. (1 m) height. The largest truck allowed on roads in Oregon without a special permit is 14 feet high by 8.5 feet wide by 75 feet long (4.3 x 2.6 x 22.9 m). The induced currents to such a vehicle oriented perpendicular to the line in a maximum field of 1.7 kV/m (at 3.28-foot height) would be less than 1.5 mA (Reilly, 1979). For smaller trucks, the maximum induced currents for perpendicular orientation to the proposed line would be less than this value. (Larger special-permitted trucks, such as triple trailers, can be up to 105 feet in length. However, because they average the field over such a long distance, the maximum induced current to a 105-foot vehicle oriented perpendicular to the 230-kV line at a road crossing would be less than 1.4 mA.) Thus, the NESC 5-mA criterion would be met for perpendicular road crossings of the proposed line. These large vehicles are not anticipated to be off highways or oriented parallel to the proposed line. Even if they were, the NESC 5-mA criterion would be met under the proposed line. As discussed below, these are worst-case estimates of induced currents at road crossings; conditions for their occurrence are rare. The conductor clearance at each road crossing would be checked during the design stage of the line to ensure that the NESC 5-mA criterion is met. Furthermore, it is BPA policy to limit the maximum induced current from vehicles to 2 mA in commercial parking lots. Line clearances would also be increased in accordance with the NESC, such as over railroads and water areas suitable for sailboating.

Several factors tend to reduce the levels of induced current shocks from vehicles:

(1) Activities are distributed over the whole right-of-way, and only a small percentage of time is spent in areas where the field is at or close to the maximum value.

(2) At road crossings, vehicles are aligned perpendicular to the conductors, resulting in a substantial reduction in induced current.

(3) The conductor clearance at road crossings may not be at minimum values because of lower conductor temperatures and/or location of the road crossing away from midspan.

(4) The largest vehicles are permitted only on certain highways.

(5) Off-road vehicles are in contact with soil or vegetation, which reduces shock currents substantially.

Induced voltages occur on objects, such as vehicles, in an electric field where there is an inadequate electrical ground. If the voltage is sufficiently high, then a spark discharge shock can occur as contact is made with the object. Such shocks are similar to "carpet" shocks that occur, for example, when a person touches a doorknob after walking across a carpet on a dry day.

In electric fields higher than will occur under the proposed line, it is theoretically possible for a spark discharge from the induced voltage on a large vehicle to ignite gasoline vapor during refueling. The probability for exactly the right conditions to occur for ignition is extremely remote. The additional clearance of conductors provided at road crossings reduces the electric field in areas where vehicles are prevalent and reduces the chances for such events. Even so, BPA recommends that vehicles should not be refueled under the proposed line unless specific precautions are taken to ground the vehicle and the fueling source (USDOE, 1995).

Under certain conditions, the electric field can be perceived through hair movement on an upraised hand or arm of a person standing on the ground under high-voltage transmission lines. The median field for perception in this manner was 7 kV/m for 136 persons; only about 12% could perceive fields of 2 kV/m or less (Deno and Zaffanella, 1982). Even in areas under the conductors at midspan, the fields at ground level would be below the levels where field perception normally occurs. Therefore, it is unlikely that the field would be perceived anywhere on the right-of-way. Where vegetation provides shielding, the field would not be perceived.

Conductive shielding reduces both the electric field and induced effects such as shocks. Persons inside a vehicle cab or canopy are shielded from the electric field. Similarly, a row of trees or a lower-voltage distribution line reduces the field on the ground in the vicinity. Metal pipes, wiring, and other conductors in a residence or building shield the interior from the transmission-line electric field.

Thus, potential impacts of electric fields can be mitigated through grounding policies, adherence to the NESC, and increased clearances above the minimums specified by the NESC. Worst-case levels are used for safety analyses but, in practice, induced currents and voltages are reduced considerably by unintentional grounding. Shielding by conducting objects, such as vehicles and vegetation, also reduces the potential for electric-field effects.

The electric fields from the proposed 230-kV line will be less than those from the line it is replacing. Therefore the potential for impacts of electric fields will be reduced from that now present on the existing right-of-way. The potential for effects from the parallel 500-kV line will remain the same.

5.2 Magnetic Field: Short-term Effects

Magnetic fields associated with transmission and distribution systems can induce voltage and current in long conducting objects that are parallel to the transmission line. As with electric-field induction, these induced voltages and currents are a potential source of shocks. A fence, irrigation pipe, pipeline, electrical distribution line, or telephone line forms a conducting loop when it is grounded at both ends. The earth forms the other portion of the loop. The magnetic field from a transmission line can induce a current to flow in such a loop if it is oriented parallel to the line. If only one end of the fence is grounded, then an induced voltage appears across the open end of the loop. The possibility for a shock exists if a person closes the loop at the open end by contacting both the ground and the conductor. The magnitude of this potential shock depends on the following factors: the magnitude of the field; the length of the object (the longer the object, the larger the induced voltage); the orientation of the object with respect to the transmission line (parallel as opposed to perpendicular, where no induction would occur); and the amount of electrical resistance in the loop (high resistance limits the current flow).

Magnetically induced currents from power lines have been investigated for many years; calculation methods and mitigating measures are available. A comprehensive study of gas pipelines near transmission lines developed prediction methods and mitigation techniques specifically for induced voltages on pipelines (Dabkowski and Taflove, 1979; Taflove and Dabkowski, 1979). Similar techniques and procedures are available for irrigation pipes and fences. Grounding policies employed by utilities for long fences reduce the potential magnitude of induced voltage.

The magnitude of the coupling with both pipes and fences is very dependent on the electrical unbalance (unequal currents) among the three phases of the line. Thus, a distribution line where a phase outage may go unnoticed for long periods of time can represent a larger source of induced currents than a transmission line where the loads are well-balanced (Jaffa and Stewart, 1981).

Knowledge of the phenomenon, grounding practices, and the availability of mitigation measures mean that magnetic-induction effects from the proposed 230-kV transmission line will be minimal.

Magnetic fields from transmission and distribution facilities can interfere with certain electronic equipment. Magnetic fields can cause distortion of the image on VDTs and computer monitors. The threshold field for interference depends on the type and size of monitor and the frequency of the field. Interference has been observed for certain monitors at fields at or below 10 mG (Baishiki et al., 1990; Banfai et al., 2000). Generally, the problem arises when computer monitors are in use near electrical distribution facilities in large office buildings. Fields from the proposed line would fall below this level at approximately 120 ft. (37 m) from the centerline.

Interference from magnetic fields can be eliminated by shielding the affected monitor or moving it to an area with lower fields. Similar mitigation methods could be applied to other sensitive electronics, if necessary. Interference from 60-Hz fields with computers and control circuits in vehicles and other equipment is not anticipated at the field levels found under and near the proposed 230-kV transmission line.

The magnetic fields from the proposed line will be less than those from the existing line that is being replaced. Therefore the potential for impacts from magnetic fields will be reduced from that on the existing right-of-way. The potential for effects from the parallel 500-kV line will remain the same.

6.0 Regulations

Regulations that apply to transmission-line electric and magnetic fields fall into two categories. Safety standards or codes are intended to limit or eliminate electric shocks that could seriously injure or kill persons. Field limits or guidelines are intended to limit electric- and magnetic-field exposures that can cause nuisance shocks or might cause health effects. In no case has a limit or standard been established because of a known or demonstrated health effect.

The proposed line would be designed to meet the NESC (IEEE, 1990), which specifies how far transmission-line conductors must be from the ground and other objects. The clearances specified in the code provide safe distances that prevent harmful shocks to workers and the public. In addition, people who live and work near transmission lines must be aware of safety precautions to avoid electrical (which is not necessarily physical) contact with the conductors. For example, farmers should not up-end irrigation pipes under a transmission or other electrical line. In addition, as a matter of safety, the NESC specifies that electric-field-induced currents from transmission lines must be below the 5 mA (“let go”) threshold deemed a lower limit for primary shock. BPA publishes and distributes a brochure that describes safe practices to protect against shock hazards around power lines (USDOE, 1995).

Field limits or guidelines have been adopted in several states and countries and by national and international organizations. Electric-field limits have generally been based on minimizing nuisance shocks or field perception. The intent of magnetic-field limits has been to limit exposures to existing levels, given the uncertainty of their potential for health effects.

There are currently no national standards in the United States for 60-Hz electric and magnetic fields. Several states have been active in establishing mandatory or suggested limits on 60-Hz electric and (in two cases) magnetic fields. Six states have specific electric-field limits that apply to transmission lines: Florida, Minnesota, Montana, New Jersey, New York, and Oregon. Florida and New York have established regulations for magnetic fields. These regulations are summarized in Table 5, adapted from TDHS Report (1989).

Electric-field limits for the states have been given in terms of maximum field or edge-of-right-of-way field, or both. The Oregon limit of 9 kV/m for electric fields is applied to areas accessible to the public (Oregon, 1980). The Oregon rule, which is found in transmission-line siting procedures also addresses grounding practices, audible noise, and radio interference.

Government agencies and utilities operating transmission systems have established design criteria that include EMF levels. BPA has maximum allowable electric fields of 9 and 5 kV/m on and at the edge of the right-of-way, respectively (USDOE, 1996). BPA also has maximum-allowable electric field strengths of 5 kV/m, 3.5 kV/m, and 2.5 kV/m for road crossings, shopping center parking lots, and commercial/ industrial parking lots, respectively. These levels are based on limiting the maximum short-circuit currents from anticipated vehicles to less than 1 mA in shopping center lots and to less than 2 mA in commercial parking lots.

Electric-field limits for overhead power lines have also been established in other countries (Maddock, 1992). Limits for magnetic fields from overhead power lines have not been explicitly established anywhere except in Florida and New York. However, general guidelines and limits on EMF have been established for occupational and public exposure in several countries and by national and international organizations.

The American Conference of Governmental Industrial Hygienists (ACGIH) sets guidelines (Threshold Limit Values or TLV) for occupational exposures to environmental agents (ACGIH, 2000). In general, a TLV represents the level below which it is believed that nearly all workers may be exposed repeatedly without adverse health effects. For EMF, the TLVs represent ceiling levels. For 60-Hz electric fields, occupational exposures should not exceed the TLV of 25 kV/m. However, the ACGIH also recognizes the potential for startle reactions from spark discharges and short-circuit currents in fields greater than 5-7 kV/m, and recommends implementing grounding practices. They recommend the use of conductive clothing for work in fields exceeding 15 kV/m. The TLV for occupational exposure to 60-Hz magnetic fields is a ceiling level of 10 G (10,000 mG) (ACGIH, 2000).

Electric and magnetic fields from various sources (including automobile ignitions, appliances, and, possibly, transmission lines) can interfere with implanted cardiac pacemakers. In light of this potential problem, manufacturers design devices to be immune from such interference. However, research has shown that these efforts have not been completely successful and that a few models of pacemakers could be affected by 60-Hz fields from transmission lines. There were also numerous models of pacemakers that were not affected by fields even larger than those found under transmission lines. Because of the known potential for interference with pacemakers by 60-Hz fields, field limits for pacemaker wearers have been established by the ACGIH. They recommend that wearers of pacemakers and similar medical-assist devices limit their exposure to electric fields of 1 kV/m or less and to magnetic fields to 1 G (1,000 mG) or less (ACGIH, 2000).

The International Committee on Non-ionizing Radiation Protection (ICNIRP), working in cooperation with the World Health Organization (WHO) has developed guidelines for occupational and public exposures to EMF (ICNIRP, 1998). For occupational exposures at 60 Hz, the recommended limits to exposure are 8.3 kV/m for electric fields and 4.2 G (4,200 mG) for magnetic fields. The electric-field level can be exceeded, provided precautions are taken to prevent spark discharge and induced current shocks. For the general public, the ICNIRP guidelines recommend exposure limits of 4.2 kV/m for electric fields and 0.83 G (830 mG) for magnetic fields (ICNIRP, 1998).

ICNIRP has also established guidelines for contact currents, which could occur when a grounded person contacts an ungrounded object in an electric field. The guideline levels are 1.0 mA for occupational exposure and 0.5 mA for public exposure.

The estimated peak electric field and magnetic field on, and at the edge of, the right-of-way of the proposed transmission line would meet limits set in all states, including Oregon. The electric fields from the proposed 230-kV line would meet the ACGIH standards, provided wearers of pacemakers and similar medical-assist devices are discouraged from unshielded right-of-way use. (A passenger in an automobile under the line would be shielded from the electric field.) The electric fields from the proposed line would meet the ICNIRP guideline for public exposure. The magnetic fields from the proposed line would be below the ACGIH and IRPA/INIRC limits. The electric fields present on the right-of-way could induce currents in ungrounded vehicles that exceeded the ICNIRP level of 0.5 mA.

7.0 Audible Noise

7.1 Basic Concepts

Audible noise (AN), as defined here, represents an unwanted sound, as from a transmission line, transformer, airport, or vehicle traffic. Sound is a pressure wave caused by a sound source vibrating or displacing air. The ear converts the pressure fluctuations into auditory sensations. AN from a source is superimposed on the background or ambient noise that is present before the source is introduced.

The amplitude of a sound wave is the incremental pressure resulting from sound above atmospheric pressure. The sound-pressure level is the fundamental measure of AN; it is generally measured on a logarithmic scale with respect to a reference pressure. The sound-pressure level (SPL) in decibels (dB) is given by:

$$SPL = 20 \log (P/P_o) dB$$

where P is the effective rms (root-mean-square) sound pressure, P_o is the reference pressure, and the logarithm (log) is to the base 10. The reference pressure for measurements concerned with hearing is usually taken as 20 micropascals (Pa), which is the approximate threshold of hearing for the human ear. A logarithmic scale is used to encompass the wide range of sound levels present in the environment. The range of human hearing is from 0 dB up to about 140 dB, a ratio of 10 million in pressure (EPA, 1978).

Logarithmic scales, such as the decibel scale, are not directly additive: to combine decibel levels, the dB values must be converted back to their respective equivalent pressure values, the total rms pressure level found, and the dB value of the total recalculated. For example, adding two sounds of equal level on the dB scale results in a 3 dB increase in sound level. Such an increase in sound pressure level of 3 dB, which corresponds to a doubling of the energy in the sound wave, is barely discernible by the human ear. It requires an increase of about 10 dB in SPL to produce a subjective doubling of sound level for humans. The upper range of hearing for humans (140 dB) corresponds to a sharply painful response (EPA, 1978).

Humans respond to sounds in the frequency range of 16 to 20,000 Hz. The human response depends on frequency, with the most sensitive range roughly between 2000 and 4000 Hz. The frequency-dependent sensitivity is reflected in various weighting scales for measuring audible noise. The A-weighted scale weights the various frequency components of a noise in approximately the same way that the human ear responds. This scale is generally used to measure and describe levels of environmental sounds such as those from vehicles or occupational sources. The A-weighted scale is also used to characterize transmission-line noise. Sound levels measured on the A-scale are expressed in units of dB(A) or dBA.

AN levels and, in particular, corona-generated audible noise (see below) vary in time. In order to account for fluctuating sound levels, statistical descriptors have been developed for environmental noise. Exceedence levels (L levels) refer to the A-weighted sound level that is exceeded for a specified percentage of the time. Thus, the L_5 level refers to the noise level that is exceeded only 5% of the time. L_{50} refers to the sound level exceeded 50% of the time. Sound-level measurements and predictions for transmission lines are often expressed in terms of exceedence levels, with the L_5 level representing the maximum level and the L_{50} level representing a median level.

Table 6 shows AN levels from various common sources. Clearly, there is wide variation. Noise exposure depends on how much time an individual spends in different locations. Outdoor noise generally does not contribute to indoor levels (EPA, 1974). Activities in a building or residence generally dominate interior AN levels. The amount of sound attenuation (reduction) provided by buildings is given in Table 7. Assuming that residences along the line route fall in the "warm climate, windows open" category, the typical sound attenuation provided by a house is about 12 dBA.

The BPA design criterion for corona-generated audible noise (L_{50}, foul weather) is 50 ±2 dBA at the edge of the ROW. This criterion has been interpreted by the state and BPA to meet Oregon Noise Control Regulations (Perry, 1982). The Environmental Protection Agency (EPA) has established a guideline of 55 dBA for the annual average day-night level (L_{dn}) in outdoor areas (EPA, 1978). In computing this value, a 10 dB correction (penalty) is added to night-time noise between the hours of 10 p.m. and 7 a.m.

7.2 Transmission-line Audible Noise

Corona is the partial electrical breakdown of the insulating properties of air around the conductors of a transmission line. In a small volume near the surface of the conductors, energy and heat are dissipated. Part of this energy is in the form of small local pressure changes that result in audible noise. Corona-generated audible noise can be characterized as a hissing, crackling sound that, under certain conditions, is accompanied by a 120-Hz hum.

Corona-generated audible noise is of concern primarily for contemporary lines operating at voltages of 345 kV and higher during foul weather. Thus in the area where the proposed 230-kV line parallels a 500-kV line, audible noise from the higher voltage line will predominate. In other areas, the proposed 230-kV line will produce some noise under foul-weather conditions.

The conductors of high-voltage transmission lines are designed to be corona-free under ideal conditions. However, protrusions on the conductor surface—particularly water droplets on or dripping off the conductors—cause electric fields near the conductor surface to exceed corona onset levels, and corona occurs. Therefore, audible noise from transmission lines is generally a foul-weather (wet-conductor) phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Based on meteorologic records near the route of the proposed transmission line, such conditions are expected to occur less than 22% of the time during the year. For a few months after line construction, residual grease or oil on the conductors can cause water to bead up on the surface. This results in more corona sources and slightly higher levels of audible noise and electromagnetic interference if the line is energized. However, the new conductors "age" in a few months, and the level of corona activity decreases to the predicted equilibrium value. During fair weather, insects and dust on the conductor can also serve as sources of corona. The proposed line has been designed with 1.600-in. (4.1-cm) diameter conductors that will yield acceptable corona levels.

7.3 Predicted Audible Noise Levels

The predicted levels of corona-generated audible noise for the proposed line operated at a voltage of 235 kV are given in Table 8. For comparison, Table 8 also gives the calculated levels for the existing lines. Audible noise levels are calculated for average voltage and average conductor heights for fair- and foul-weather conditions. The calculated median level (L_{50}) during foul weather at the edge of the proposed Santiam - Bethel right-of-way is about 39 dBA, which is less than that from the existing Santiam - Chemawa 230-kV line. Where the proposed Santiam - Bethel line parallels the Marion - Santiam 500-kV line, noise from the higher-voltage line will predominate and there would be no change in noise levels from existing conditions. For this configuration, the noise at the edge of the right-of-way near the proposed line would be 47 dBA.

During fair-weather conditions, which occur about 78% of the time, audible noise levels at the edge of the right-of-way would be about 20 dBA lower (if corona were present). These lower levels could be masked by ambient noise on and off the right-of-way.

7.4 Discussion

The calculated foul-weather corona noise levels for the proposed line would be less than those under the existing conditions and comparable to or less than those from existing 230-kV lines in Oregon. During fair weather, noise from the conductors might be perceivable on the right-of-way, but beyond the right-of-way it would likely be masked or so low as to not be perceived even during foul weather when ambient noise is higher.

Off the right-of-way, the levels of audible noise from the proposed line would be well below the 55 dBA level that can produce interference with speech outdoors. Since residential buildings provide significant sound attenuation (-12 dBA with windows open; -24 dBA with windows closed), the noise levels off the right-of-way would be well below the 45 dBA level required for interference with speech indoors and well below the 35 dBA level where sleep interference can occur (EPA, 1973; EPA, 1978). Since corona is a foul-weather phenomenon, people tend to be inside with windows possibly closed, providing additional attenuation when corona noise is present. In addition, ambient noise levels can be high during such periods (due to rain hitting foliage or buildings), and can mask corona noise.

The 39-dBA and 47-dBA levels would meet the BPA design criterion and, hence, the Oregon Noise Control Regulations for transmission lines. The 2 dBA decrease in noise at the edge of the right-of-way associated with the proposed line would probably not be discernible.

The computed annual L_{dn} level for transmission lines operating in areas with about 22% foul weather is about $L_{dn} = L_{50} + 1$ dB (Bracken, 1987). Therefore, assuming such conditions in the Santiam - Bethel area, the estimated L_{dn} at the edge of the right-of-way would be approximately 40 or 48 dBA, which is below the EPA L_{dn} guideline of 55 dBA.

7.5 Conclusion

Along the proposed line route, there would be slight decreases, or no change, in the perceived noise above ambient levels during foul weather at the edges of the right-of-way. Along the existing corridor, the corona-generated noise during foul weather would be masked to some extent by naturally occurring sounds such as wind and rain on foliage. During fair weather, the noise off the right-of-way from the proposed line would probably not be detectable above ambient levels. However, noise from the existing 500-kV line could be perceived as much as under existing conditions. The noise levels from the proposed line would be below levels identified as causing interference with speech or sleep. The audible noise from the transmission line would be below EPA guideline levels and would meet the BPA design criterion that complies with the Oregon State noise regulations.

8.0 Electromagnetic Interference

8.1 Basic Concepts

Corona on transmission-line conductors can also generate electromagnetic noise in the frequency bands used for radio and television signals. The noise can cause radio and television interference (RI and TVI). In certain circumstances, corona-generated electromagnetic interference (EMI) can also affect communications systems and other sensitive receivers. Interference with electromagnetic signals by corona-generated noise is generally associated with lines operating at voltages of 345 kV or higher. This is especially true of interference with television signals. The 1.600-in. (4.1-cm) diameter conductor used in the design of the proposed 230-kV line will mitigate corona generation and thus keep radio and television interference levels at acceptable levels.

Spark gaps on distribution lines and on low-voltage wood-pole transmission lines are a more common source of RI/TVI than is corona from high-voltage electrical systems. This gap-type interference is primarily a fair-weather phenomenon caused by loose hardware and wires. The proposed transmission line would be constructed with modern hardware that eliminates such problems and therefore minimizes gap noise. Consequently, this source of EMI is not anticipated for the proposed line.

No state has limits for either RI or TVI. In the United States, electromagnetic interference from power transmission systems is governed by the Federal Communications Commission (FCC) Rules and Regulations presently in existence (FCC, 1988). A power transmission system falls into the FCC category of "incidental radiation device," which is defined as "a device that radiates radio frequency energy during the course of its operation although the device is not intentionally designed to generate radio frequency energy." Such a device "shall be operated so that the radio frequency energy that is emitted does not cause harmful interference. In the event that harmful interference is caused, the operator of the device shall promptly take steps to eliminate the harmful interference." For purposes of these regulations, harmful interference is defined as: "any emission, radiation or induction which endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radio communication service operating in accordance with this chapter" (FCC, 1988: Vol II, part 15. 47CFR, Ch. 1).

Electric power companies have been able to work quite well under the present FCC rule because harmful interference can generally be eliminated. It has been estimated that more than 95% of power-line sources that cause interference are due to gap-type discharges. These can be found and completely eliminated, when required to prevent interference (USDOE, 1980). Complaints related to corona-generated interference occur infrequently. This is especially true with the advent of cable television and satellite television, which are not subject to corona-generated interference. Mitigation of corona-generated interference with conventional radio and television receivers can be accomplished in several ways, such as use of a directional antenna or relocation of an existing antenna (USDOE, 1977; USDOE, 1980; Loftness et al., 1981).

8.2 Radio Interference (RI)

Radio reception in the AM broadcast band (535 to 1605 kilohertz (kHz)) is most often affected by corona-generated EMI. FM radio reception is rarely affected. Generally, only residences very near to transmission lines can be affected by RI. The IEEE Radio Noise Design Guide identifies an acceptable limit of fair-weather RI as expressed in decibels above 1 microvolt per meter (dBμV/m) of about 40 dBμV/m at 100 ft. (30 m) from the outside conductor (IEEE Committee Report, 1971). As a general rule, average levels during foul weather (when the conductors are wet) are 16 to 22 dBμV/m higher than average fair-weather levels.

8.3 Predicted RI Levels

Table 9 gives the predicted fair- and foul-weather RI levels at 100 ft. (30 m) from the outside conductor for the proposed 230-kV line in the two corridor configurations. Median foul-weather levels would be about 17 dB higher than the fair-weather levels. The predicted L_{50} fair-weather level at the edge of the right-of-way is 34 dBμV/m for 235-kV line operation; at 100 ft. (30 m) from the outside conductor, the level is 26 dBμV/m. Predicted fair-weather L_{50} levels are lower than that from the existing 230-kV Santiam - Chemawa 230-kV line. Predictions indicate that fair-weather RI will meet the IEEE

40 dBμV/m criterion at distances greater than about 10 ft. (3 m) from the outside conductor of the proposed line.

8.4 Television Interference (TVI)

Corona-caused TVI occurs during foul weather and is generally of concern for transmission lines with voltages of 345 kV or above, and only for conventional receivers within about 600 ft. (183 m) of a line. As is the case for RI, gap sources on distribution and low-voltage transmission lines are the principal observed sources of TVI. The use of modern hardware and construction practices for the proposed line would minimize such sources.

8.5 Predicted TVI Levels

Table 10 shows TVI levels predicted at 100 ft. (30 m) from the outside conductor of the proposed line operating at 235 kV and from existing lines. At this distance, the foul-weather TVI level predicted for the proposed line is 10 dBμV/m. This level is lower than that from the existing Santiam - Chemawa 230-kV line. Replacement of the existing line with the proposed line will reduce TVI levels along the right-of-way.

Other forms of TVI from transmission lines are signal reflection (ghosting) and signal blocking caused by the relative locations of the transmission structure and the receiving antenna with respect to the incoming television signal. The proposed structures are steel and larger than the existing wood structures; they could cause reflection or ghosting and affect reception in rare instances. Television systems that operate at higher frequencies, such as satellite receivers, are not affected by corona-generated TVI. Cable television systems are similarly unaffected.

Interference with television reception can be corrected by any of several approaches: improving the receiving antenna system; installing a remote antenna; installing an antenna for TV stations less vulnerable to interference; connecting to an existing cable system; or installing a translator (cf. USDOE, 1977). BPA has an active program to identify, investigate, and mitigate legitimate RI and TVI complaints. It is anticipated that any instances of TVI caused by the proposed line could be effectively mitigated.

8.6 Interference with Other Devices

Corona-generated interference can conceivably cause disruption on other communications bands such as the citizen’s (CB) and mobile bands. However, mobile-radio communications are not susceptible to transmission-line interference because they are generally frequency modulated (FM). Similarly, cellular telephones operate at a frequency of about 900 MHz, which is above the frequency where corona-generated interference is prevalent. In the unlikely event that interference occurs with these or other communications, mitigation can be achieved with the same techniques used for television and AM radio interference. However, the addition of the proposed line would lower interference levels in the corridor; consequently, no impact is anticipated.

8.7 Conclusion

Predicted EMI levels for the proposed 230-kV transmission line are lower than those that already exist 230-kV lines; no impacts of corona-generated interference on radio, television, or other reception are anticipated above those already present. Furthermore, if interference should occur, there are various methods for correcting it: BPA has a program to respond to legitimate complaints.

9.0 Other Corona Effects

Corona is visible as a bluish glow or as bluish plumes. On the proposed 230-kV line, corona levels would be very low, so that corona on the conductors would be observable only under the darkest conditions and only with the aid of binoculars, if at all. Without a period of adaptation for the eyes and without intentional looking for the corona, it would not be noticeable.

When corona is present, the air surrounding the conductors is ionized and many chemical reactions take place, producing small amounts of ozone and other oxidants. Ozone is approximately 90% of the oxidants, while the remaining 10% is composed principally of nitrogen oxides. The national primary ambient air quality standard for photochemical oxidants, of which ozone is the principal component, is 235 micrograms/cubic meter) or 120 parts per billion. The maximum incremental ozone levels at ground level produced by corona activity on the proposed transmission line during foul weather would be much less than 1 part per billion. This level is insignificant when compared with natural levels and fluctuations in natural levels.

10.0 Summary

Electric and magnetic fields from the proposed transmission line have been characterized using well-known techniques accepted within the scientific and engineering community. The expected electric-field levels from the proposed line at minimum design clearance would be less than those from the existing line in the corridor and comparable to, or less than, those from other 230-kV lines in Oregon and elsewhere. The expected magnetic-field levels from the proposed line would be less than those from the existing line that would be replaced and comparable to, or less than, those from other 230-kV lines in Oregon and elsewhere.

The peak electric field expected under the proposed line would be 2.5 kV/m; the maximum value at the edge of the right-of-way would be about 0.4 kV/m. Clearances at road crossings would be increased to reduce the peak electric-field value to 1.7 kV/m.

Under maximum current conditions, the maximum magnetic fields under the proposed line would be 96 mG; at the edge of the right-of-way nearest to the proposed 230-kV line, the magnetic field would be 29 or 26 mG, depending on whether the line parallels an existing 500-kV line or not.

The electric and magnetic fields from the proposed line would meet regulatory limits for public exposure in Oregon and other states with limits. As long as cardiac pacemaker wearers are discouraged from using the right-of-way, the field levels meet the guidelines for exposure established by ACGIH and ICNIRP.

Short-term effects from transmission-line fields are well understood and can be mitigated. Nuisance shocks arising from electric-field induced currents and voltages could be perceivable on the right-of-way of the proposed line. BPA will ground permanent conducting objects during and after construction to mitigate against such occurrences. Since the fields from the proposed line are less than those from the existing line on the corridor, the potential for such effects could be reduced.

Corona-generated audible noise from the line would be less than from the existing 230-kV transmission lines on the corridor. Audible noise levels would be in compliance with noise regulations in Oregon and would be below levels specified in EPA guidelines.

Corona-generated electromagnetic interference from the proposed line would be less than that from the existing 230-kV line on the corridor and would remain below limits identified as acceptable. In the unlikely event that legitimate complaints arise, BPA has a mitigation program to identify and correct reception problems.

List of References Cited

ACGIH (American Conference of Governmental Industrial Hygienists). 2000. 2000 TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists, Cincinnati. 192 pages.

Baishiki, R.S.; Johnson, G.B.; Zaffanella, L.E.; Bracken, T.D.; Sussman, S.S.; Rauch, G.B.; and Silva, J.M. 1990. Studies of Power System Magnetic Fields: Characterization of Sources in Residential Environments, Measurement of Exposure, Influence On Computer Screens. (36-104) CIGRE, Paris, France. 10 pages.

Banfai, B.; Karady, G.G.; Kim, C.J.; and Maracas, K.B. 2000. Magnetic field effects on CRT computer monitors. IEEE Trans. on Power Delivery 15, 307-312.

Bassen, H.; Casamento, J.; and Crowl, B. 1991. Reduction of electric and magnetic field emissions from electric blankets (Meeting abstract). *In*: Bioelectromagnetics Society, 13th Annual Meeting, 23-27 June, Salt Lake City. Bioelectromagnetics Society, New York, 20.

Bowman, J.D.; Garabrant, D.H.; Sobel, E.; and Peters, J.M. June 1988. Exposures to Extremely Low Frequency (ELF) Electromagnetic Fields in Occupations With Elevated Leukemia Rates. Applied Industrial Hygienics, 3(6, June):189-194.

Bracken, T.D. 1987. Audible Noise from High Voltage Transmission Facilities. A Briefing Paper Prepared for State of Florida Department of Environmental Regulation. (DER Contract No. SP122) State of Florida Department of Environmental Regulation.

Bracken, T.D. 1990. The EMDEX Project: Technology Transfer and Occupational Measurements, Volumes 1-3 Interim Report. EPRI Report EN-7048. (EPRI EN-7048) Electric Power Research Institute, Palo Alto, CA.

Chartier, V.L. April 1983. Empirical Expressions for Calculating High Voltage Transmission Corona Phenomena, First Annual Seminar Technical Career Program for Professional Engineers. Bonneville Power Administration, Portland, Oregon. April 1983, 75-82.

Chartier, V.L.; and Stearns, R.D. January 1981. Formulas for Predicting Audible Noise from Overhead High Voltage AC and DC Lines. IEEE Transactions on Power Apparatus and Systems, PAS-100(No. 1, January 1981):121-129.

Dabkowski, J.; and Taflove, A. May/June 1979. Prediction Method for Buried Pipeline Voltages Due to 60 Hz AC Inductive Coupling. Part II: Field Test Verification. IEEE Transactions on Power Apparatus and Systems, PAS-98(3, May/June):788-794.

Deno, D.W.; and Zaffanella, L. 1982. Field effects of overhead transmission lines and stations. Chap. 8. *In*: Transmission Line Reference Book: 345 KV and Above. Second ed. (Ed: LaForest, J.J.). Electric Power Research Institute, Palo Alto, CA, 329-419.

EPA (Environmental Protection Agency). July 1973. Public Health and Welfare Criteria for Noise. (No. 500/9-73-002, July 27, 1973.) U.S. Environmental Protection Agency, Washington, D.C.

EPA. 1974. Information On Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety. (No. PB-239 429.) U.S. Environmental Protection Agency, Washington, D.C.

EPA. 1978. Protective Noise Levels. Condensed Version of EPA Levels Document. (No. PB82-138827) U.S Environmental Protection Agency, Washington, DC.

FCC (Federal Communications Commission). 1988. Federal Communications Commission Rules and Regulations. 10-1-88 ed. Vol. II part 15, 47 CFR, Ch. 1.

Florig, H.K.; and Hoburg, J.F. 1988. Electric and Magnetic Field Exposure Associated With Electric Blankets. Project Resume. Contractor's Review. U.S. Department of Energy/Electric Power Research Institute.

Florig, H.K.; Hoburg, J.F.; and Morgan, M.G. April 1987. Electric Field Exposure from Electric Blankets. IEEE Transactions on Power Delivery, PWRD-2(2, April):527-536.

Gauger, J. September 1985. Household Appliance Magnetic Field Survey. IEEE Transactions on Power Apparatus and Systems, 104(9, September):2436-2445.

Harvey, S.M. 1983. Analysis of operator exposure to electric fields from video display units. Chap. 2. In Video Display Units--Characterization of Electric and Magnetic Fields. (Ontario Hydro Research Division Report # 83-503-K) (Ed: Walsh, M.L.). Ontario Hydro, Toronto, 31-56.

Heroux, P. 1987. 60-Hz Electric and Magnetic Fields Generated By a Distribution Network. Bioelectromagnetics, 8(2):135-148.

ICNIRP (International Committee on Non-ionizing Radiation Protection). April 1998. Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz). Health Physics, 74(4, April):1-32.

IEEE (Institute of Electrical and Electronics Engineers, Inc.). 1978. Electric and Magnetic Field Coupling from High Voltage AC Power Transmission Lines -- Classification of Short-Term Effects On People. IEEE Transactions on Power Apparatus and Systems, PAS-97:2243-2252.

IEEE. 1987. IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines. ANSI/IEEE Std. 644-1987, New York, NY.

IEEE. 1990. National Electrical Safety Code. 1990 ed. Institute of Electrical and Electronics Engineers, Inc., New York, NY. 432 pages.

IEEE Committee Report. March/April 1971. Radio Noise Design Guide for High Voltage Transmission Lines. IEEE Transactions on Power Apparatus and Systems, PAS-90(No. 2, March/April):833-842.

IEEE Committee Report. October 1982. A Comparison of Methods for Calculating Audible Noise of High Voltage Transmission Lines. IEEE Transactions on Power Apparatus and Systems, 101(10, October):4090-4099.

ITT Research Institute. 1984. Representative Electromagnetic Field Intensities Near the Clam Lake (WI) and Republic (MI) ELF Facilities. Report Prepared for Naval Electronics Systems

Command, PME 110 E Washington, D.C. 20360. (Under contract N00039-84-C0070.) ITT Research Institute, Chicago, IL. 60 pages.

Jaffa, K.C.; and Stewart, J.B. March 1981. Magnetic Field Induction from Overhead Transmission and Distribution Power Lines On Buried Irrigation Pipelines. IEEE Transactions on Power Apparatus and Systems, PAS-100(3, March):990-1000.

Keesey, J.C.; and Letcher, F.S. 1969. Minimum Thresholds for Physiological Responses to Flow of Alternating Electric Current Through the Human Body At Power-Transmission Frequencies. (Report No. 1) Naval Medical Research Institute, Project MR 005.08-0030B, Bethesda, MD. 25 pages.

Loftness, M.O.; Chartier, V.L.; and Reiner, G.L. 1981. EMI Correction Techniques for Transmission Line Corona. (August 18-20, 1981, pp. 351-361.) Proceedings of the 1981 IEEE International Symposium on Electromagnetic Compatibility, Boulder, CO.

Maddock, B.J. September 1992. Guidelines and Standards for Exposure to Electric and Magnetic Fields At Power Frequencies. (Panel 2-05, CIGRE meeting August 30-September 5, 1992) CIGRE, Paris.

Olsen, R.G.; Schennum, S.D.; and Chartier, V.L. April 1992. Comparison of Several Methods for Calculating Power Line Electromagnetic Interference Levels and Calibration With Long Term Data. IEEE Transactions on Power Delivery, 7(April, 1992):903-913.

Oregon, State of. 1980. Oregon Administrative Rules Chapter 345, Division 80. Energy Facility Siting Council standards relating to public health and safety, 934-80-055.

Perry, D. 1982. Sound Level Limits from BPA Facilities. BPA memorandum, May 26, 1982; Department of Environmental Quality, Noise Control Regulations, Chapter 340, Oregon Administrative Rules, Division 35, March 1, 1978.

Reilly, J.P. 1979. Electric Field Induction on Long Objects—A Methodology for Transmission Line Impact Studies. IEEE Transactions on Power Apparatus and Systems, PAS-98(6, Nov/Dec):1841-1852.

Sheppard, A.R.; and Eisenbud, M. 1977. Biological Effects of Electric and Magnetic Fields of Extremely Low Frequency. New York University Press, New York.

Silva, M.; Hummon, N.; Rutter, D.; and Hooper, C. 1989. Power Frequency Magnetic Fields in the Home. IEEE Transactions on Power Delivery, 4:465-478.

Stopps, G.J.; and Janischewskyj, W. 1979. Epidemiological Study of Workers Maintaining HV Equipment and Transmission Lines in Ontario. (Canadian Electrical Association Research Report) Canadian Electrical Association, Montreal. 82 pages.

Taflove, A.; and Dabkowski, J. May/June 1979. Prediction Method for Buried Pipeline Voltages Due to 60 Hz AC Inductive Coupling. Part I: Analysis. IEEE Transactions on Power Apparatus and Systems, PAS-98(3, May/June):780-787.

TDHS Report. March 1989. EMF Rule Becomes Law; Hillsborough County Commission Challenges. Transmission/Distribution Health & Safety Report, 7(9, 31 March):1-3.

TDHS Report. August 1990. Updates: New York. Transmission/Distribution Health & Safety Report, 8(7, 31 August):4.

USDOE (U.S. Department of Energy), Bonneville Power Administration. March 1977. A Practical Handbook for the Location, Prevention and Correction of Television Interference from Overhead Power Lines. Portland, OR.

USDOE, Bonneville Power Administration. May 1980. A Practical Handbook for the Correction of Radio Interference from Overhead Powerlines and Facilities. (May 1980.) Portland, OR.

USDOE, Bonneville Power Administration. 1995. Living and Working Around High-Voltage Power Lines. (DOE/BP-799). Portland, OR. 9 pages.

USDOE, Bonneville Power Administration. 1996. Electrical and Biological Effects of Transmission Lines: A Review. (DOE/BP 2938 December 1996 1M) Portland, OR.

USDOE, Bonneville Power Administration. undated. "Corona and Field Effects" Computer Program (Public Domain Software). Bonneville Power Administration, P.O. Box 491-ELE, Vancouver, WA 98666.

Zaffanella, L.E. 1993. Survey of Residential Magnetic Field Sources. Vol. 1: Goals, results, and conclusions. (EPRI TR-102759-V1, Project 3335-02) Electric Power Research Institute, Palo Alto, CA.

Zaffanella, L.E.; and Kalton, G.W. 1998. Survey of personal magnetic field exposure, Phase II: 1000-person survey. Interim Report. EMF RAPID Program Engineering Project #6. Enertech Consultants, Lee, MA.

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Table 1: Physical and electrical characteristics of Santiam - Bethel Project corridors

	New Line	Existing Corridors	
Configuration	**I**	**I**	**II**
Description	**Santiam - Bethel/Santiam - Chemawa 230-kV**	**Santiam - Chemawa 230-kV**	**Marion - Santiam No. 1 & No. 2 500-kV**
Voltage, kV Maximum/Average[1]	242/235	242/235	550/540, 0/0
Peak Current, A Existing/Proposed	–/755, –/644	1043/–	-889/-992, 0/0
Electric Phasing	B C A B C A	C B A	B B A C A C
Clearance, ft. Minimum/Average[1]	31/43	31/43	38/47
Centerline Distance from Santiam - Bethel, ft.	–	–	125
Centerline distance to edge of right-of-way (ROW), ft.	62.5	62.5	82.5
Tower configuration	Vertical double-circuit	Horizontal	Delta double-circuit
Phase spacing, ft.	24.5H, 40.5H 18V	27H	25.5H, 36.75V
Conductor: #/Diameter, in.	1/1.600	1/1.100	3/1.302

1 Average voltage and average clearance used for corona calculations.

Table 2: Possible corridors for Santiam - Bethel Project

Configuration	Description of other lines in corridor with Santiam - Bethel/Santiam - Chemawa 230-kV line	Miles
I	Santiam - Bethel/Santiam - Chemawa 230-kV double-circuit line only	15.2
II	BPA Marion - Santiam 500-kV No. 1 and No. 2 double circuit line	1.5

Table 3: Calculated electric fields for configurations of the proposed Santiam - Bethel/Santiam - Chemawa 230-kV line operated at maximum voltage. Configurations are described in Tables 1 and 2.

a) Configuration I: Santiam - Bethel/Santiam - Chemawa 230-kV line only

Configuration	**Proposed I**		**Existing**	
ROW width, ft. (m)	125 (38)		125 (38)	
Line	Santiam - Bethel/Santiam - Chemawa 230-kV		Santiam - Chemawa 230-kV	
Clearance	Min.	Avg.	Min.	Avg.
Peak field, kV/m	2.5	1.5	3.0	1.8
Edge of ROW, kV/m	0.3	0.4	1.3	1.1

b) Configuration II: Santiam - Bethel/Santiam - Chemawa 230-kV and Marion - Santiam 500-kV No. 1 and No. 2 lines

Configuration	**Proposed II**				**Existing**			
ROW width, ft. (m)	270 (82)				270 (82)			
Line	Santiam - Bethel/ Santiam - Chemawa 230-kV		Marion - Santiam No. 1 and No. 2 500-kV		Santiam - Chemawa 230-kV		Marion - Santiam No. 1 and No. 2 500-kV	
Clearance	Min.	Avg.	Min.	Avg.	Min.	Avg.	Min.	Avg.
Peak field, kV/m	2.4	1.4	8.1	4.5	3.0	1.8	8.1	4.5
Edge of ROW, kV/m	0.3	0.3	2.5	2.6	1.3	1.1	2.5	2.6

Table 4: Calculated magnetic fields for configurations of the proposed Santiam - Bethel/Santiam - Chemawa 230-kV line operated at maximum current. Configurations are described in Tables 1 and 2.

a) Configuration I: Santiam - Bethel/Santiam - Chemawa 230-kV line only

Configuration	**Proposed I**		**Existing**	
ROW width, ft. (m)	125 (38)		125 (38)	
Line	Santiam - Bethel/Santiam - Chemawa 230-kV		Santiam - Chemawa 230-kV	
Clearance	Min.	Avg.	Min.	Avg.
Peak field, mG	87	50	218	139
Edge of ROW, mG	26	24	78	62

b) Configuration II: Santiam - Bethel/Santiam - Chemawa 230-kV and Marion - Santiam 500-kV No. 1 and No. 2 lines

Configuration	**Proposed II**				**Existing**			
ROW width, ft. (m)	270 (82)				270 (82)			
Line	Santiam - Bethel/ Santiam - Chemawa 230-kV		Marion - Santiam No. 1 and No. 2 500-kV		Santiam - Chemawa 230-kV		Marion - Santiam No. 1 and No. 2 500-kV	
Clearance	Min.	Avg.	Min.	Avg.	Min.	Avg.	Min.	Avg.
Peak field, mG	94	58	130	67	211	135	108	57
Edge of ROW, kV/m	29	24	52	39	80	65	50	38

Table 5: States with transmission-line field limits

STATE AGENCY	WITHIN RIGHT-OF-WAY	AT EDGE OF RIGHT-OF-WAY	COMMENTS
a. 60-Hz ELECTRIC FIELD LIMIT, kV/m			
Florida Department of Environmental Regulation	8 (230 kV) 10 (500 kV)	2	Codified regulation, adopted after a public rulemaking hearing in 1989.
Minnesota Environmental Quality Board	8	–	12-kV/m limit on the High-Voltage Direct Current (HVDC) nominal electric field.
Montana Board of Natural Resources and Conservation	7[1]	1[2]	Codified regulation, adopted after a public rulemaking hearing in 1984.
New Jersey Department of Environmental Protection	–	3	Used only as a guideline for evaluating complaints.
New York State Public Service Commission	11.8 (7,11)[1]	1.6	Explicitly implemented in terms of a specified right-of-way width.
Oregon Facility Siting Council	9	–	Codified regulation, adopted after a public rulemaking hearing in 1980.
b. 60-Hz MAGNETIC FIELD LIMIT, mG			
Florida Department of Environmental Regulation	–	150 (230 kV) 200 (500 kV)	Codified regulations, adopted after a public rulemaking hearing in 1989.
New York State Public Service Commission	–	200	Adopted August 29, 1990.

1 At road crossings
2 Landowner may waive limit

Sources: TDHS Report, 1989;TDHS Report, 1990

Table 6: Common noise levels

Sound Level, dBA	Noise Source or Effect
128	Threshold of pain
108	Rock-and-roll band
80	Truck at 50 ft. (15.2 m)
70	Gas lawnmower at 100 ft. (30 m)
60	Normal conversation indoors
50	Moderate rainfall on foliage
50	Edge of 500-kV right-of-way during rain
40	Refrigerator
25	Bedroom at night
0	Hearing threshold

Adapted from: USDOE, 1996.

Table 7: Typical sound attenuation (in decibels) provided by buildings

	Windows opened	Windows closed
Warm climate	12	24
Cold climate	17	24

Source: EPA, 1978.

Table 8: Predicted foul-weather audible noise (AN) levels at edge of right-of-way (ROW) for proposed Santiam - Bethel/Santiam - Chemawa 230-kV line. AN levels expressed in decibels on the A-weighted scale (dBA). L_{50} and L_5 denote the levels exceeded 50 and 5 percent of the time, respectively. For the parallel-line configurations[1], the AN level at the edge of the proposed Santiam - Bethel ROW is given first.

Configuration[1]	Foul-weather AN					
	Proposed			Existing		
	ROW ft. (m)	L_{50}, dBA	L_5, dBA	ROW ft. (m)	L_{50}, dBA	L_5, dBA
I	125 (38)	39	43	125 (38)	41	44
II	270 (82)	47, 52	51, 55	270 (82)	47, 52	51, 55

1 Configurations are described in Tables 1 and 2.

Table 9: Predicted fair-weather radio interference (RI) levels at 100 feet (30.5 m) from the outside conductor of the proposed Santiam - Bethel/Santiam - Chemawa 230-kV line. RI levels given in decibels above 1 microvolt/meter (dBμV/m) at 1.0 MHz. L_{50} denotes level exceeded 50 percent of the time. For the parallel-line configurations the RI level on the side of the proposed Santiam - Bethel ROW is given first.

Configuration[1]	Fair-weather RI	
	Proposed	Existing
	L_{50}, dBμV/m	L_{50}, dBμV/m
I	26	28
II	30, 41	30, 41

1 Configurations are described in Tables 1 and 2.

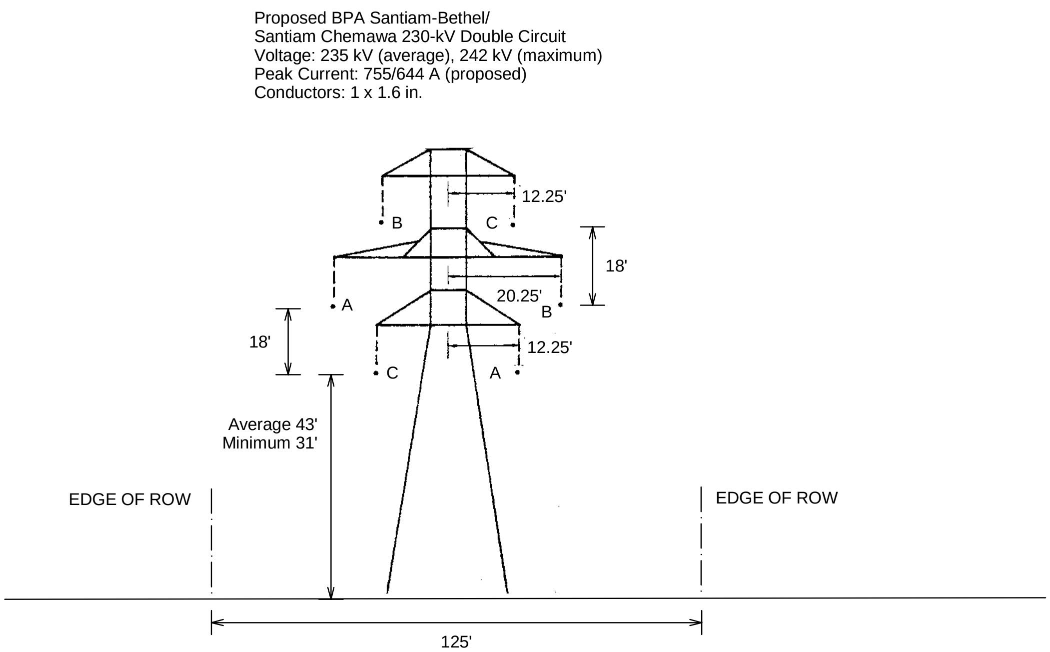
Table 10: Predicted maximum foul-weather television interference (TVI) levels predicted at 100 feet (30.5 m) from the outside conductor of the proposed Santiam - Bethel/Santiam - Chemawa 230-kV line. TVI levels given in decibels above 1 microvolt/meter (dBμV/m) at 75 MHz. For the parallel-line configurations, the TVI level on the side of the proposed Santiam - Bethel ROW is given first.

Configuration[1]	Foul-weather TVI	
	Proposed	Existing
	L_5 (foul), dBμV/m	L_5 (foul), dBμV/m
I	10	15
II	12, 27	15, 27

1 Configurations are described in detail in Tables 1 and 2.

Figure 1: Configurations for proposed Santiam - Bethel/Santiam - Chemawa 230-kV line: a) proposed line with no parallel lines (Configuration I); and b) proposed line with parallel 500-kV line (Configuration II).

a) Proposed line with no parallel lines (Configuration I) (not to scale)



b) Proposed line with parallel 500-kV line (Configuration II) (not to scale)

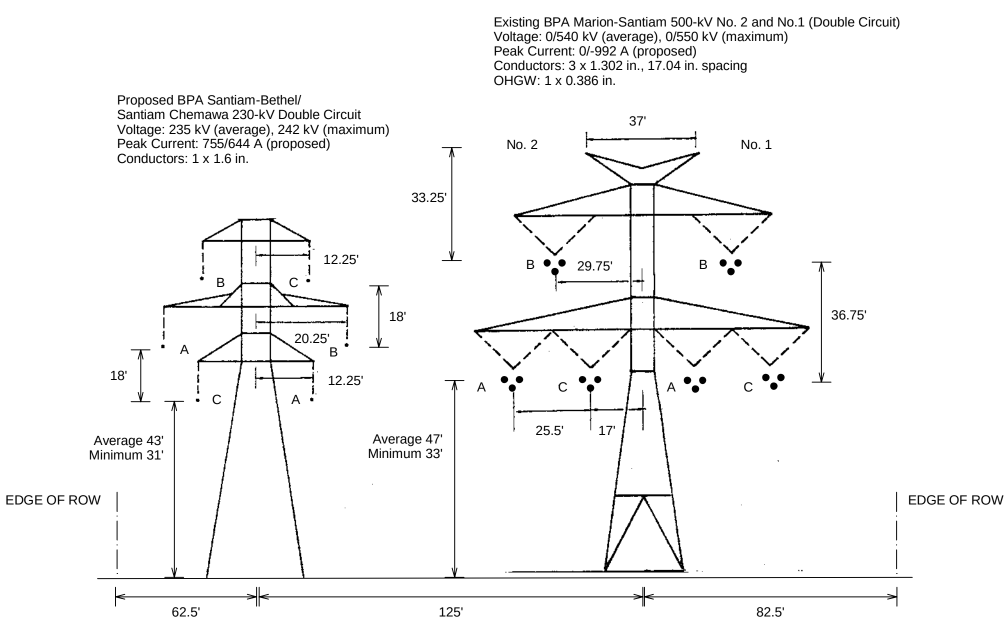
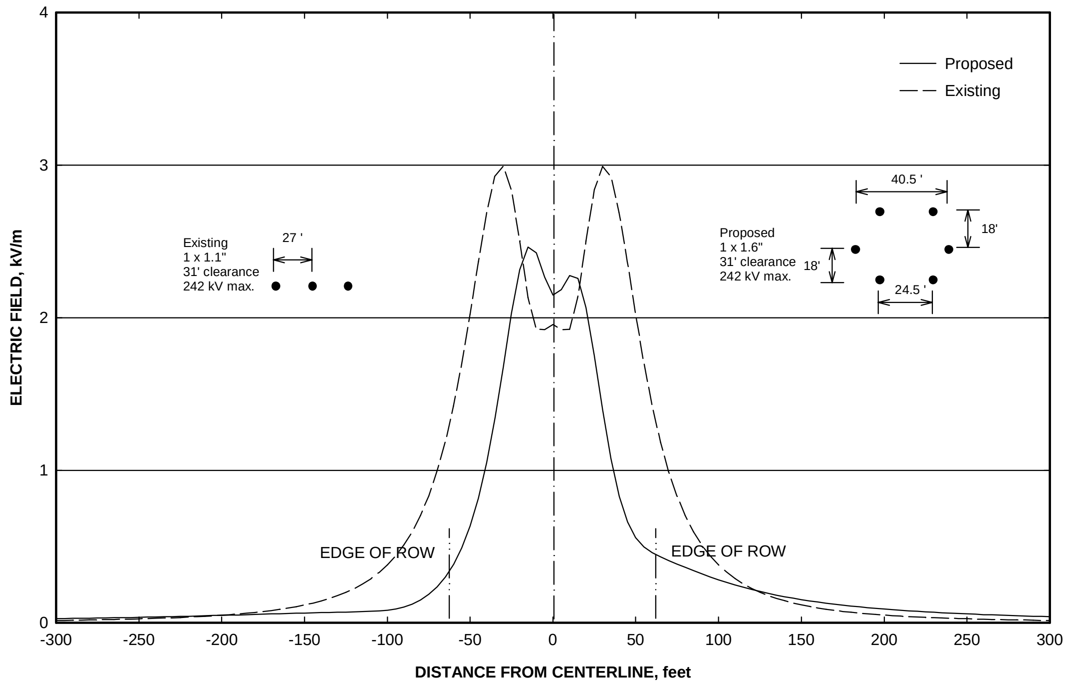


Figure 2: Electric-field profiles for configurations of proposed Santiam - Bethel/Santiam - Chemawa 230-kV line: a) proposed line with no parallel line (Configuration I); and b) proposed line with parallel 500-kV line (Configuration II). Fields for maximum voltage and minimum clearances are shown.

a) Proposed line with no parallel line (Configuration I).



b) Proposed line with parallel 500-kV line (Configuration II)

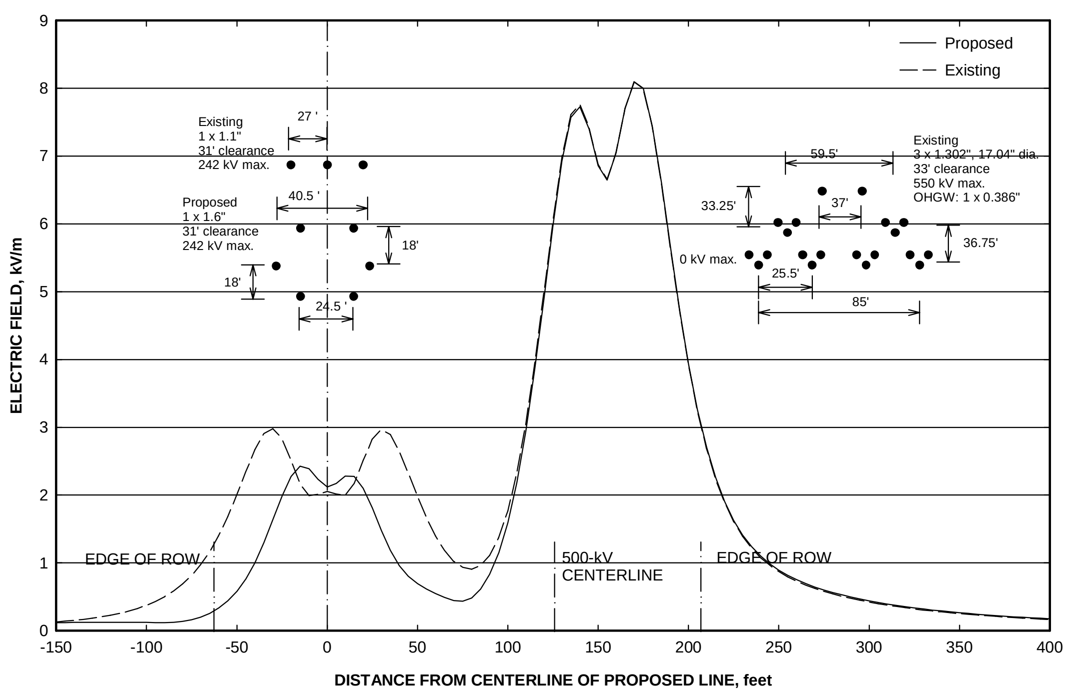
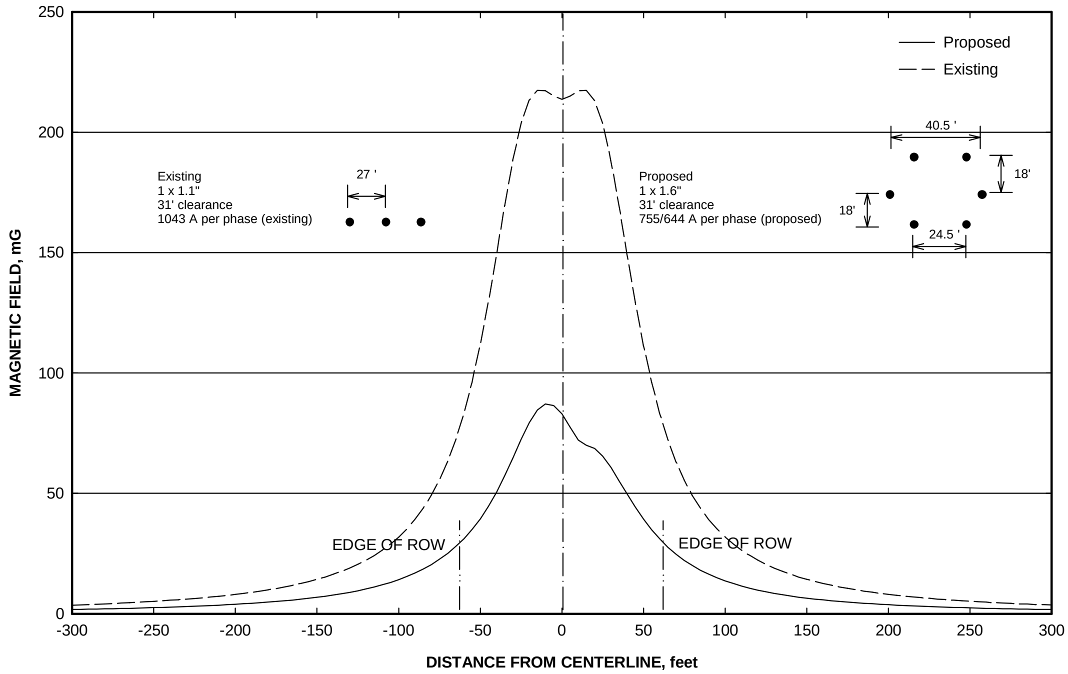
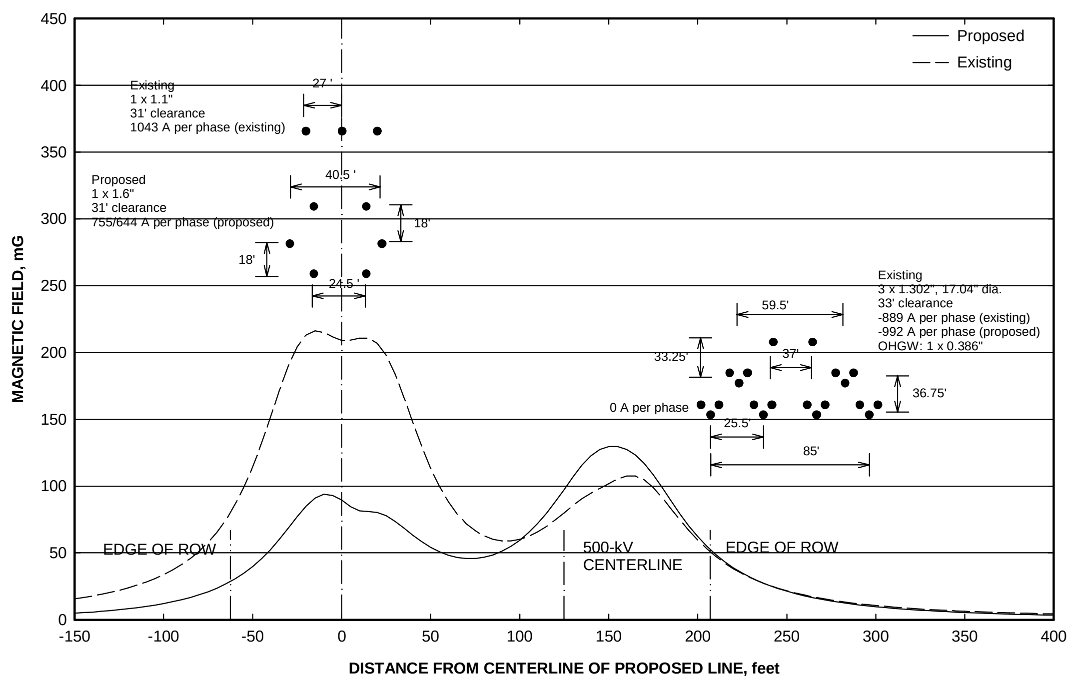


Figure 3: Magnetic-field profiles for configurations of the proposed Santiam - Bethel/Santiam - Chemawa 230-kV line for maximum current conditions:
a) proposed line with no parallel line (Configuration I); and b) proposed line with parallel 500-kV line (Configuration II).

a) Proposed line with no parallel line (Configuration I)



b) Proposed line with parallel 500-kV line (Configuration II).



SANTIAM-BETHEL TRANSMISSION PROJECT

APPENDIX B:

ASSESSMENT OF RESEARCH REGARDING EMF AND HEALTH AND ENVIRONMENTAL EFFECTS

June 2001

Prepared by

Exponent™

and

T. Dan Bracken, Inc.

for

Bonnneville Power Administration

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APPENDIX B: ASSESSMENT OF RESEARCH REGARDING EMF AND HEALTH AND ENVIRONMENTAL EFFECTS

1.0 Introduction

Over the last 20 years, research has been conducted in the United States (U.S.) and around the world to examine whether exposures to electric and magnetic fields (EMF) at 50/60 hertz (Hz) from electric power lines are a cause of cancer, or adversely affect human health. The research included epidemiology studies that suggested a link with childhood for some types of exposures, as well as other epidemiology studies that did not; it also included lifetime animal studies, which showed no evidence of adverse health effects. Comprehensive reviews of the research conducted by governmental and scientific agencies in the U.S. and in the United Kingdom (UK) had examined the research, and did not find a basis for imposing additional restrictions (NIEHS, 1999; IEE, 2000).

The Bonneville Power Administration (BPA) requested that Exponent update the BPA on research on EMF and health and in relation to exposures that might occur near the Bethel-Santiam Transmission Project.

This update concentrates on recent major research studies to explain how they contribute to the assessment of effects of EMF on health (Section 2). The focus is on both epidemiologic and laboratory research, because these research approaches provide different and complementary information for determining whether an environmental exposure can affect human health. Section 3, Ecological Research, reviews studies of potential effects of EMF on plants and animals in the natural environment. No additional studies of environmental effects were found in our search of the scientific literature through May 2001.

2.0 Health

2.1 The NIEHS Report and Research Program

In 1998, the NIEHS completed a comprehensive review of the scientific research on health effects of EMF. The NIEHS had been managing a research program that Congress funded in 1996, in response to questions regarding exposure to EMF from power sources. The program was known as the RAPID Program (Research and Public Information Dissemination Program). The NIEHS convened a panel of scientists (the “Working Group”) to review and evaluate the RAPID Program research and other research. Their report, *Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields*, was completed in July 1998 (NIEHS, 1998).

The director of the NIEHS prepared a health risk assessment of EMF and submitted his report to Congress in June 1999 (NIEHS, 1999). Experts at NIEHS, who had considered the previous Working Group report, reports from four technical workshops, and research that became available after June 1998, concluded as follows:

> The scientific evidence suggesting that ELF-EMF [extremely low frequency-electric and magnetic field] exposures pose any health risk is weak. The strongest evidence for health

> effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed adults. . . . In contrast, the mechanistic studies and animal toxicology literature fail to demonstrate any consistent pattern . . . . No indication of increased leukemias in experimental animals has been observed. . . . The lack of consistent, positive findings in animal or mechanistic studies weakens the belief that this association is actually due to ELF-EMF, but it cannot completely discount the epidemiology findings. . . . The NIEHS does not believe that other cancers or other non-cancer health outcomes provide sufficient evidence of a risk to currently warrant concern (pp. 9-10).

Although the results of the RAPID research are described in some detail in the 1998 report, many of the studies had not been published in the peer-reviewed literature. Recognizing the need to have these results reviewed and considered for publication, the NIEHS arranged for a special edition of the journal *Radiation Research* (Radiation Research, 153(5), 2000) to be devoted to this topic.[1]

2.2 Update of Research Related to Cancer

This update includes studies of residential or occupational exposures to EMF and leukemia that became available this year (2001), including several reports from the California Department of Health Services. That Department conducted a workshop in 1999 to discuss epidemiologic research on EMF and health. The reports presented at this workshop were published in January 2001 as a supplement to the journal, *Bioelectromagnetics*. Many of the papers were technical discussions of methodology issues in epidemiologic studies of EMF, including discussions of how better to understand the conflicting results reported in previous studies (Neutra and Del Pizzo, 2001). For example, one paper evaluated epidemiology studies to determine whether systematic errors occurred in selection of cases and controls, or measurement of exposure. Although such systematic errors, or bias, occurred in some studies, there was insufficient information to assess the effect on results (Wartenberg, 2001a). Other researchers discuss epidemiologic approaches to study how possible confounding factors, such as the age and type of home and traffic density, might affect the interpretation of studies of EMF and childhood cancer (Langholz, 2001; Reynolds et al., 2001).

For this update, we review papers from this workshop that provide new information or statistical analyses. Several of the studies are “meta-analyses,” an approach that incorporates statistical methods to analyze differences and aggregate the results of smaller studies. The section below includes a review of meta-analyses of the studies of childhood leukemia through 1999, and a meta-analysis of studies of breast cancer in adults (Erren, 2001).

2.2.1 Epidemiology Studies of Children

The question of power lines and childhood cancer has been based on the assumption that the relevant exposure associated with power lines is the magnetic field, rather than the electric field. This assumption rests on the fact that electric fields are shielded from the interior of homes (where people spend the vast majority of their time) by walls and vegetation, while magnetic fields are not. The magnetic field in the vicinity of a power line results from the flow of current; higher currents result in higher levels of magnetic fields.

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[1] See, for instance, the articles cited in the **List of References** under Balcer- Kubiczek, Boorman, Loberg, and Ryan.

Epidemiologic studies report results in the form of statistical associations. The term "statistical association" is used to describe the tendency of two things to be linked or to vary in the same way, such as level of exposure and occurrence of disease. However, statistical associations are not automatically an indication of cause and effect, because the interpretation of numerical information depends on the context, including (for example) the nature of what is being studied, the source of the data, how the data were collected, and the size of the study. The larger studies and more powerful studies of EMF have not reported convincing statistical associations between power lines and childhood leukemia (e.g., Linet et al., 1997; McBride et al., 1999; UKCCS, 1999). Despite the larger sample size, these studies usually had a limited number of cases exposed over 2 or 3 milligauss (mG).

Epidemiology studies

The following discussion briefly describes major studies.

- A study from Germany included 502 children with leukemia and 1,289 control children (Schuz et al., 2001). Measurements of magnetic-field intensity (50 Hz) were taken for 24 hours in the child's bedroom. The results were calculated for daytime or nighttime levels in the bedroom, rather than for the child's overall 24-hour exposure. The authors report an association with leukemia for mean daytime magnetic-field exposures that might have been due to chance. They reported an association between mean nighttime magnetic-field levels and leukemia for the highest exposed group (4 mG or higher; 9 cases). The assessment of exposure by mean field levels in the bedroom did not link magnetic-field levels to any specific source. The authors note in their conclusions that " . . . fewer than one-third of all stronger magnetic fields were caused by high-voltage powerlines. . . . " (Schuz et al., 2001: 734).

  Several aspects of the study detract from the validity of the results: the estimate included a broad margin of error because only a small number of cases was exposed at the higher levels, and many eligible cases and controls did not participate, which means that the responders may not represent the population and results could be biased. Another concern is that these magnetic field measurements were taken in 1997, long after the relevant exposure period for cases diagnosed in 1990-1994. Magnetic-field levels may have changed over time, as electricity usage changed.

- A study from British Columbia, Canada, included 462 children who had been diagnosed with leukemia and an equal number of children without leukemia for comparison (McBride et al., 1999). Magnetic-field exposure was assessed for each of the children in several ways: personal monitors were worn in a backpack for 48 hours, a monitor took measurements in the bedroom for 24 hours, the wiring outside the house was rated by potential exposure level (wire codes), and measurements were taken around the outside perimeter of the homes. (Wire codes are a method of estimating relative exposure intensity based on the configuration of the power lines.) Regardless of the method used to estimate magnetic-field exposure, the magnetic-field exposure of children who had leukemia was not greater than that of the children in the comparison group.

- A study conducted in Ontario, Canada reported on the magnetic-field exposure of a smaller group of children (Green et al., 1999a). No increased risk estimates were found with the average magnetic fields in the bedroom or the interior, or with any of the three methods of estimating exposure from wire-configuration codes. A still smaller group of 88 children with leukemia and their controls wore personal monitors to measure magnetic fields (Green et al., 1999b). Associations with magnetic fields were reported in some of the analyses, but most of the risk estimates had a broad margin of error, and major methodological problems in the study preclude any clear interpretation of the findings.

- The United Kingdom Childhood Cancer Study, the largest study to date, included a total of 1073 childhood leukemia cases (UKCCS, 1999). Exposure was assessed by spot measurements in the home (bedroom and family room) and school, and summarized by averaging these over time. No evidence was found to support the idea of an increased risk of leukemia from exposures to magnetic fields from power sources inside or outside of the home.

- The UKCCS investigators had obtained magnetic-field measurements on only a portion of the cases in their study (UKCCS, 1999). To obtain additional information, they used a method to assess exposure to magnetic fields without entering homes; they were thus able to analyze 50% more subjects (UKCCS, 2000). For all these children, they measured distances to power lines and substations. This information was used to calculate the magnetic field from these external field sources, based on power-line characteristics related to production of magnetic fields. The results of the second UKCCS study showed no evidence for an association with leukemia for magnetic fields calculated to be between 1 mG and 2 mG, 2 mG and 4 mG, or 4 mG or greater at the residence, in contrast to the weak association reported for measured fields of 4 mG or greater in the first report (UKCCS, 1999).

Researchers have proposed that the associations that are sometimes reported between childhood leukemia and power lines may be due to other factors that can confound the analysis. One example is heavy traffic, which may occur near power lines and can increase the levels of potentially carcinogenic chemicals in the area. Earlier studies had reported associations between traffic density and childhood cancer (Savitz et al., 1988). If power lines were more common in areas that had higher traffic density, then the increased air pollution might explain an association between power lines and childhood cancer. However, more recent studies seem to eliminate this possibility. In a study of 90 cases of childhood leukemia, Reynolds et al. (2001) found no evidence of an association with traffic density. In a larger study that included 986 cases of childhood leukemia, no association was found with high traffic-density exposure during pregnancy or childhood (Raaschou-Nielsen et al., 2001). In addition, no association with childhood leukemia or brain cancer was found for exposures to benzene or nitrogen dioxide. Associations were reported between Hodgkin's disease and exposure to each of these chemicals.

Meta-analyses of studies of leukemia

Recently, researchers reanalyzed the data from previous epidemiology studies of magnetic fields and childhood leukemia (Ahlbom et al., 2000; Greenland et al., 2000). The researchers pooled the data on individuals from each of the studies, creating a study with a larger number of subjects and therefore greater statistical power than any single study. A pooled analysis is preferable to other types of meta-analyses in which the results from several studies are combined from grouped data obtained from the published studies. These analyses focused on studies that assessed exposure to magnetic fields using 24-hour measurements or calculations based on the characteristics of the power lines and current load. Both Ahlbom et al. and Greenland et al. used exposure categories of <0.1 microtesla (μT) (<1 mG) as a reference category. The statistical results of these analyses can be summarized as follows:

- The pooled analyses provided no indication that wire codes are more strongly associated with leukemia than measured fields.

- Pooling these data corroborates an absence of an association between childhood leukemia and magnetic fields for exposures below 0.3 μT (3 mG).

- Pooling these data results in a statistical association with leukemia for exposures greater than 0.3 or 0.4 μT (3-4 mG).

The authors are appropriately cautious in the interpretation of their analyses, and they clearly identify the limitations in their evaluation of the original studies. Magnetic fields above 0.3 μT in residences are estimated to be rather rare, about 3% in the U.S. (Zaffanella, 1993). Limitations include sparse data (few cases) to adequately characterize a relationship between magnetic fields and leukemia, uncertainties related to pooling different magnetic-field measures without evidence that all of the measures are comparable, and incomplete and limited data on important confounders (other risk factors for disease that may distort the analysis) such as housing type and traffic density.

A meta-analysis of the data from epidemiologic studies of childhood leukemia studies was presented at the California Workshop and recently published (Wartenberg, 2001b). This meta-analysis did not have the advantage of obtaining and pooling the data on all of the individuals in the studies, unlike those published before it (Ahlbom et al., 2000; Greenland et al., 2000). Rather than individual data, Wartenberg (2001b) used an approach that extracted the published results, reported as grouped data from several published studies. He used 19 studies overall, after excluding 7 studies that had insufficient data on individuals or deficiencies in the exposure assessment data. He reported a weak association for a) "proximity to electrical facilities" based on wire codes or distance, and b) magnetic-field level over 2 mG, based on either calculations from wiring and loading characteristics (if available) or on spot magnetic-field measurements. The results show more cases than controls exposed to measured or calculated fields above 2 mG. The author concludes that the analysis supports an association, although the size of the effect is small to moderate, but also notes "limitations due to design, confounding, and other biases may suggest alternative interpretations" (Wartenberg, 2001b:S-100).

The results of this meta-analysis are not directly comparable to previous ones regarding fields of 3 or 4 mG because the analysis was not based on individual data. The comparison of grouped data used different exposure cut points for the analysis and different criteria for the comparison group. None of these three analyses (Ahlbom et al., 2000; Greenland et al., 2000; Wartenberg, 2001b) includes the results of the UK analysis of over 3000 cases based on calculated fields, which found no association between EMF and childhood cancer, regardless of the exposure level.

2.2.2 Epidemiology Studies of Adults

Studies of adults with certain types of cancer, such as brain cancer, breast cancer, or leukemia, have reported associations with exposure to magnetic fields at residences, but results have not been consistent across studies. Contradictory results among studies argue against a conclusion that the association reflects a cause-and-effect relationship. In their assessments of risk, scientists give most weight to studies that include more people, obtain more detailed and individual exposure assessments, and/or include people who have higher exposures.

A study of 492 adult cases of brain cancer in California included measurements of magnetic fields taken in the home and at the front door, and considered the types of power-line wiring (Wrensch et al., 1999). The authors report no evidence of increased risk with higher exposures, no association with type of power line, and no link with levels measured at the front door.

A number of recent studies of breast cancer focused on electric blankets as a source of high exposure. Electric blankets are assumed to be one of the strongest sources of EMF exposure in the home. Three studies of electric blanket use found no evidence that long-term use increased the risk of breast cancer. Women who developed breast cancer reported no difference in total use of electric blankets, use in recent years, or use many years in the past:

- Gammon et al. (1998) reported that, even for those who kept the blanket on most of the time, no increase in risk was found for those who had longer duration of use (measured in months).

- A study of 608 breast cancer cases also found no evidence of increased use of electric blankets or other home appliances in cases compared to controls, and no indication of increasing risk with a longer time of use (Zheng et al., 2000).

- In a cohort of over 120,000 female nurses, data were obtained on known risk factors for breast cancer as well as electric-blanket use (Laden et al., 2000). For a large subset of this group, the questions about exposure were asked before the disease occurred, a step taken to eliminate bias in recalling exposure.

Erren (2001) reported the results of a meta-analysis of the studies of breast cancer, in which the results of 24 different studies in women were statistically aggregated. When the results of all 24 studies were pooled, including studies of workplace exposures, the estimate indicated an association between EMF and a small excess breast cancer risk. The pooled results for exposure to EMF in the vicinity of electrical facilities did not show an association with breast cancer, nor did the results for exposure to EMF from appliance use. However, the meta-analysis also showed a lack of consistency among the results of the individual studies, a broad variation in the designs, and a wide range of methods used to assess exposure. No adjustments were made to the data to give increased weight to studies based on more comprehensive exposure assessments. The author also noted that the weak statistical association might be an artifact (a result of chance or unforeseen error) rather than an indication of a cause-and-effect relationship (Erren, 2001).

2.2.3 Laboratory Studies of EMF

Laboratory studies complement epidemiologic studies of people because the effects of heredity, diet, and other health-related exposures of animals can be better controlled or eliminated. The assessment of EMF and health, as for any other exposure, includes chronic, long-term studies in animals (*in vivo* studies) and studies of changes in genes or other cellular processes observed in isolated cells and tissues in the laboratory (*in vitro*).

Although the results of the RAPID Program were described in some detail in the NIEHS reports (NIEHS, 1998), many of the studies had not been published in the peer-reviewed literature. The RAPID research program included studies of four biological effects, each of which had been observed in only one laboratory. These effects are as follows: effects on gene expression, increased intracellular calcium in a human cell line, proliferation of cell colonies on agar, and increased activity of the enzyme ornithine decarboylase (ODC). Some scientists have suggested that these biological responses are signs of possible adverse health effects of EMF. It is standard scientific procedure to attempt to replicate results in other laboratories, because artifacts and investigator error can occur in scientific investigations. Replications, often using more experiments or more rigorous protocols, help to ensure objectivity and validity. Attempts at replication can substantiate and strengthen an observation, or they may discover the underlying reason for the observed response.

Studies in the RAPID program reported no consistent biological effects of EMF exposure on gene expression, intracellular calcium concentration, growth of cell colonies on agar, or ODC activity (Boorman et al., 2000b). For example, Loberg et al. (2000) and Balcer-Kubiczek et al. (2000) studied the expression of hundreds of cancer-related genes in human mammary or leukemia cell lines. They found no increase in gene expression with increased intensity of magnetic fields. To test the experimental procedure, they used X-rays and treatments known to affect the genes. These are known as positive controls and, as expected, caused gene expression in exposed cells.

Scientists have concluded that the combined animal bioassay results provide no evidence that magnetic fields cause, enhance, or promote the development of leukemia and lymphoma, or mammary cancer (e.g., Boorman et al., 1999; McCormick et al., 1999; Boorman et al., 2000 a, b; Anderson et al., 2001).

2.2.4 Summary Regarding Cancer

Epidemiology studies do not support the idea that EMF from power lines increase the risk of cancers in adults. The latest epidemiologic studies of childhood cancer, considered in the context of the other data, provide no persuasive and consistent evidence that leukemia in children is causally associated with magnetic fields measured at the home, calculated based on distance and current loading, or with wire codes. Recent meta-analyses reported no association between childhood cancer and magnetic fields below 2 or 3 mG. Although some association was reported for fields above this level, fields at most residences are likely to be below 3 or 4 mG. The authors of each of these analyses list several biases and problems that render the data inconclusive, and prevent resolution of the inconsistencies in the epidemiologic data. For this reason, laboratory studies can provide important complementary information. Large, well-conducted animal studies provide no convincing evidence that exposure increases the risk of cancer. Animal studies, and studies of initiation and promotion, provide no basis to conclude that EMF increases leukemia, lymphoma, breast, brain, or any other type of cancer.

2.3 Research Related to Reproduction

Previous epidemiologic studies reported no association with birth weight or fetal growth retardation after exposure to sources of relatively strong magnetic fields, such as electric blankets, or sources of typically weaker magnetic fields such as power lines (Bracken et al., 1995; Belanger et al., 1998).

A recent epidemiology study examined miscarriages[2] in relation to exposures to magnetic fields from electric bed-heating (electric blankets, heated waterbeds and mattress pads), which result in higher exposures than residential fields in general (Lee et al., 2000). The researchers assessed exposure prior to the birth (a prospective study) and included information to control for potential confounding factors (other exposures and conditions that affect the risk of miscarriage). This study had a large number of cases and high participation rates. Miscarriage rates were lower among users of electric bed heating.

Studies of laboratory animals exposed to pure 60-Hz fields have shown no increase in birth defects, no multigenerational effects, and no changes that would indicate an increase in miscarriage or loss of fertility (e.g., Ryan et al., 1999; Ryan et al., 2000). Exposed and unexposed litters were no different in the amount of fetal loss and the number and type of birth defects, indicating no reproductive effect of EMF.

In summary, the recent evidence from epidemiology and laboratory studies provides no indication that exposure to power-frequency EMF has an adverse effect on reproduction, pregnancy, or growth and development of the embryo. The results of these recent studies are consistent with the conclusions of the NIEHS.

2.4 Other Recent Reviews by Scientific Advisory Groups

Reviews of the scientific research regarding EMF and health by Health Council of the Netherlands and the Institute of Electrical Engineers of the UK were published in 2000. The National Radiological

[2] The medical term for miscarriage is spontaneous abortion.

Protection Board of Great Britain (NRPB) Advisory Group on Non-Ionizing Radiation published the most recent review in 2001. This review includes research published in 2000, and includes the most comprehensive discussion of the individual research studies.

2.4.1 National Radiological Protection Board of Great Britain (NRPB) Advisory Group on Non-Ionising Radiation

The conclusions from the report prepared by the NRPB's Advisory Group on Non-Ionising Radiation (AGNIR) on extremely low frequency (ELF) EMF and the risk of cancer are consistent with previous reviews. Members from universities, medical schools, and cancer research institutes reviewed the reports of experimental and epidemiological studies, including reports in the literature in 2000. Their general conclusions are as follows:

> Laboratory experiments have provided no good evidence that extremely low frequency electromagnetic fields are capable of producing cancer, nor do human epidemiological studies suggest that they cause cancer in general. There is, however, some epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukaemia in children. In practice, such levels of exposure are seldom encountered by the general public in the UK [or in the US] (NRPB, 2001: 164).

The group further recognizes that the scientific evidence suggesting that exposure to power-frequency electromagnetic fields poses an increased risk of cancer is very weak. Virtually all of the cellular, animal, and human laboratory evidence provides no support for an increased risk of cancer incidence following such exposure to power frequencies, although sporadic positive findings have been reported. In addition, the epidemiological evidence is, at best, weak.

These conclusions of the Advisory Group are consistent with previous reviews by the NIEHS (1999) and the Health Council of the Netherlands (HCN, 2000). The NRPB response to the Advisory Group report states "the review of experimental studies by [the Advisory Group] AGNIR gives no clear support for a causal relationship between exposure to ELF-EMFs and cancer" (NRPB, 2001:1).

2.4.2 Health Council of the Netherlands

The Health Council of the Netherlands has prepared an update of its 1992 Advisory Report on exposure to electromagnetic fields (0 Hz to 10 MHz) (HCN, 2000). Members of the Expert Committee prepared the report. The Expert Committee based its analysis on the review and summaries of the studies provided in the NIEHS (1998) and concurred with the views of the director of the NIEHS (1999). For the update, the Committee evaluated a number of publications that appeared after these reports, e.g., McBride et al. (1999) and Green et al. (1999a), and wrote:

> The committee thinks that the quality of the relevant epidemiological research has improved considerably since the publication of the advisory report in 1992. Even so, this research has not resulted in unequivocal, scientifically reliable conclusions (p. 15).

The Council emphasizes that the associations with EMF reported in epidemiologic studies are strictly statistical and do not demonstrate a cause-and-effect relationship. In their view, experimental research does not demonstrate a causal link or a mechanism to explain EMF as a cause of disease in humans. They concluded that there is no reason to recommend measures to limit residence near overhead power lines (HCN, 2000).

2.4.3 Institution of Electrical Engineers (IEE) of Great Britain

One of the recent reviews was that of the Institution of Electrical Engineers (IEE) of Great Britain (IEE, 2000). In 1992, the IEE set up a Working Party whose eight members, with broad expertise in the health sciences, review the relevant scientific literature and prepare reports of their views. Their conclusion is based on recent major epidemiologic studies and the scientific literature built up over the past 20 years. In May 2000, the Working Party concluded " . . . that there is still not convincing scientific evidence showing harmful effects of low level electromagnetic fields on humans" (IEE, 2000:1).

3.0 Ecological Research

Scientists have studied the effects of high-voltage transmission lines on many plant and animal species in the natural environment. In this section, we briefly review the research on the effects of EMF on ecological systems to assess the likelihood of adverse impacts. In addition to the comprehensive review of research on this topic by wildlife biologists at the BPA (Lee et al., 1996), we searched the published scientific literature for more recent studies published between 1995 and May 2001.

3.1 Fauna

The habitat on the transmission-line right-of-way and surrounding area shields most wildlife from electric fields. Vegetation in the form of grasses, shrubs, and small trees largely shields small ground-dwelling species such as mice, rabbits, foxes, and snakes from electric fields. Species that live underground, such as moles, woodchucks, and worms, are further shielded from electric fields by the soil. Hence, large species such as deer and domestic livestock (e.g., sheep and cattle) have greater potential exposures to electric fields since they can stand taller than surrounding vegetation. However, the duration of exposure for deer and other large animals is likely to be limited to foraging bouts or the time it takes them to cross under the line. Furthermore, all species would be exposed to higher magnetic fields under a transmission-line than elsewhere, as the vegetation and soil do not provide shielding from this aspect of the transmission-line electrical environment.

Field studies have been performed in which the behavior of large mammals in the vicinity of high-voltage transmission lines was monitored. No effects of electric or magnetic fields were evident in two studies from the northern United States on big game species, such as deer and elk, exposed to a 500-kV transmission line (Goodwin 1975; Picton et al., 1985). In such studies, a possible confounding factor is audible noise. Audible noise associated with high-voltage power transmission lines (with voltages greater than 110-kV) is due to corona. Audible noise generated by transmission lines reaches its highest levels in inclement weather (rain or snow).

Much larger populations of animals that might spend time near a transmission line are livestock that graze under or near transmission lines. To provide a more sensitive and reliable test for adverse effects than informal observation, scientists have studied animals continuously exposed to fields from the lines in relatively controlled conditions. For example, grazing animals such as cows and sheep have been exposed to high-voltage transmission lines and their reproductive performance examined (Lee et al., 1996). In some studies, the effects of exposure over one or more successive breedings were examined (Angell et al., 1990). Compared to unexposed animals in a similar environment, it was found that the exposure did not affect reproductive functions or pregnancy of cows (Algers and Hennichs, 1985; Algers and Hultgren, 1987).

A group of investigators from Oregon State University, Portland State University, and other academic centers evaluated the effects of long-term exposure to EMF from a 500-kV transmission line operated by

BPA on various cellular aspects of immune response, including the production of proteins by leukocytes (IL-1 and IL-2) of sheep. In previous unpublished reports, the researchers found differences in IL-1 activity between exposed and control groups. However, in their most recent replication, the authors found no evidence of differences in these measures of immune function. The sheep were exposed to 27 months of continuous exposure to EMF, a period of exposure much greater than the short, intermittent exposures of sheep grazing under transmission lines. Mean exposures of magnetic and electric fields were 3.5-3.8 µT (35-38 mG) and 5.2-5.8 kV/m, respectively (Hefeneider et al., 2001).

Scientists from Illinois Institute of Technology (IIT) monitored the possible effects of electric and magnetic fields on fauna and flora in Michigan and Wisconsin from 1969 – 1997 to evaluate the effects of an above-ground, military-communications antenna operating at 76 Hz. The antenna produces EMF similar in physical characteristics to those produced by high-voltage transmission lines, but of much lower intensity. This study included embryonic development, fertility, postnatal growth, maturation, aerobic metabolism, and homing behavior, and showed no adverse impacts of ELF electric and magnetic fields on the animals (NRC, 1997).

The hormone melatonin, secreted at night by the pineal gland, plays a role in animals that are seasonal breeders. Studies in laboratory mice and rats have suggested that exposure to electric and/or magnetic fields might affect levels of the hormone melatonin, but results have not been consistent (Wilson et al., 1981; Holmberg, 1995; Kroeker et al., 1996; Vollrath et al., 1997; Huuskonen et al., 2001). However, when researchers examined sheep and cattle exposed to EMF from transmission lines exceeding 500-kV, they found no effect on the levels of the hormone melatonin in blood, weight gain, onset of puberty, or behavior in sheep and cattle (Stormshak et al., 1992; Lee et al., 1993; Lee et al., 1995; Thompson et al., 1995; Burchard et al., 1998).

Another part of the IIT study examined the effect of the antenna system fields on the growth, development, and homing behavior of birds. Studies of embryonic development (Beaver et al., 1993), fertility, postnatal growth, maturation, aerobic metabolism, and homing behavior showed no adverse impacts of ELF electric and magnetic fields on the animals (NRC, 1997). Fernie and colleagues studied the effects of continuous EMF exposure of raptors to an electric field of 10 kV/m in a controlled, laboratory setting. The exposure was designed to mimic exposure to a 765-kV transmission line. Continuous EMF exposure was found to reduce hatching success, yet increase egg size, fledging success, and embryonic development (Fernie et al., 2000). In a study of the effects on body mass and food intake of reproducing falcons, the authors found that EMF lengthened the photoperiod as a result of altered melatonin levels in the male species, yet concluded that "EMF effects on adult birds may only occur after continuous, extended exposure," which is not likely to occur from resting on power lines (Fernie and Bird, 1999:620).

Several avian species are reported to use the earth's magnetic field as one of the cues for navigation. It has been proposed that deposits of magnetite in specialized cells in the head are the mechanism by which the birds can detect variations in the inclination and intensity of a dc magnetic field (Kirschvink and Gould, 1981; Walcott et al., 1988). In early studies of transmission lines, it was reported that the migratory patterns of birds appeared to be altered near transmission lines (Southern, 1975; Larkin and Sutherland, 1977). However, these studies were of crude design, and Lee et al. (1996) concluded that, "During migration, birds must routinely fly over probably hundreds (or thousands) of electrical transmission and distribution lines. We are not aware of any evidence to suggest that such lines are disrupting migratory flights" (p. 4-59). No further studies on this topic were identified in the literature.

Bees, like birds, are able to detect the earth's dc magnetic fields. They are known to use magnetite particles, which are contained in an abdominal organ, as a compass (Kirschvink and Gould, 1981). In the laboratory, they are able to discriminate between a localized magnetic anomaly and a uniform background dc magnetic field (Walker et al., 1982; Kirschvink et al., 1992).

Greenberg et al. (1981) studied honeybee colonies placed near 765-kV transmission lines. They found that hives exposed to electric fields of 7 kV/m had decreased hive weight, abnormal amounts of propolis (a resinous material) at hive entrances, increased mortality and irritability, loss of the queen in some hives, and a decrease in the hive's overall survival compared to hives that were not exposed. Exposure to electric fields of 7-12 kV/m may induce a current or heat the interior of the hive; however, placing the hive farther from the line, shielding the hive, or using hives without metallic parts eliminates this problem. ITT studied the effects of EMF on bees exposed to the 76-Hz antenna system at lower intensities and concluded that these behavioral effects of "ELF-EMF impacts are absent or at most minimal" (NRC, 1997:102).

Reptiles and amphibians contribute to the overall functioning of the forest ecosystems. However, little research has been performed on the effects of EMF on reptiles and amphibians in their natural habitat.

3.2 Flora

Numerous studies have been carried out to assess the effect of exposure of plants to transmission-line electric and magnetic fields. These studies have involved both forest species and agriculture crops. Researchers have found no adverse effects on plant responses, including seed germination, seedling emergence, seedling growth, leaf area per plant, flowering, seed production, germination of the seeds, longevity, and biomass production (Lee et al., 1996).

The only confirmed adverse effect of transmission lines on plants was reported for transmission lines with voltages above 1200-kV. For example, Douglas Fir trees planted within 15 m of the conductors were shorter than trees planted away from the line. Shorter trees are believed to result from corona-induced damage to the branch tips. Trees between 15 and 30 m away from the line suffered needle burns, but those 30 m and beyond were not affected (Rogers et al., 1984). These effects would not occur at the lower field intensities expected beyond the right-of-way of the proposed 500-kV transmission line.

3.3 Summary

The habitat on the transmission-line rights-of-way and surrounding areas shield smaller animals from electric fields produced by high-voltage transmission lines; thus, vegetation easily shields small animals from electric fields. The greatest potential for larger animals to be exposed to EMF occurs when they are passing beneath the lines. Studies of animal reproductive performance, behavior, melatonin production, immune function, and navigation have found minimal or no effects of EMF. Past studies have found little effect of EMF on plants; no recent studies of plants growing near transmission lines have been performed. In summary, the literature published to date has shown little evidence of adverse effects of EMF from high-voltage transmission lines on wildlife and plants. At the field intensities associated with the proposed 230-kV transmission line, no adverse effects on wildlife or plants are expected.

LIST OF REFERENCES

Ahlbom, A.; Day, N.; Feychting, M.; Roman, E.; Skinner, J.; Dockerty, J.; Linet, M.; Michealis, J.; Olsen, J.H.; Tynes, T.; Verasalo, P.K. 2000. A pooled analysis of magnetic fields and childhood leukaemia. British Journal of Cancer, 83(5): 692-698.

Algers, B.; and Hennichs, K. 1985. The effect of exposure to 400-kV transmission lines on the fertility of cows: a retrospective cohort study. Preventive Veterinary Medicine 3: 351-361.

Algers, B.; and Hultgren, J. 1987. Effects of long-term exposure to a 400-kV, 50-Hz transmission line on estrous and fertility in cows. Preventive Veterinary Medicine 5: 21-36.

Anderson, L.E.; Morris, J.E.; Miller, D.L.; Rafferty, C.N.; Ebi, K.L.; Sasser, L.B. 2001. Large granular lymphocytic (LGL) leukemia in rats exposed to intermittent 60 Hz magntic fields. Bioelectromagnetics, 22:185-193.

Angell, R.F.; Schott, M.R.; Raleigh, R.J.; Bracken, T.D. 1990. Effects of a high-voltage direct-current transmission line on beef cattle production. Bioelectromagnetics. 11(4):273-82.

Balcer-Kubiczek, E.K.; Harrison, G.H.; Davis, C.C.; Haas, M.L.; Koffman, B.H. 2000. Expression analysis of human HL60 exposed to 60 Hz square or sine-wave magnetic fields. Radiation Research, 153(5): 670-678.

Beaver, D.L.; Hill, R.W.; Lederle, P.E. 1993. Assessment of the effects of extremely low frequency electromagnetic radiation on growth and maturation in nestling tree swallows and deer mice. Electricity and Magnetism in Biology and Medicine. M. Blank, ed., San Francisco Press, Inc., pp. 925-926.

Belanger, K.; Leaderer, B.; Hellenbrand, K.; Holford, T.R.; McSharry, J.; Power, M.E.; Bracken, M.B. 1998. Spontaneous abortion and exposure to electric blankets and heated water beds. Epidemiology, 9:36-42.

Boorman, G.A.; Anderson, L.E.; Morris, J.E.; Sasser, L.B.; Mann, P.C.; Grumbein, S.L.; Hailey, J.R.; McNally, A.; Sills, R.C.; Haseman, J.K. 1999. Effects of 26-week magnetic field exposure in a DMBA initiation-promotion mammary glands model in Sprague-Dawley rats. Carcinogenesis, 20: 899-904.

Boorman, G.A.; McCormick, D.J.; Ward, J.M.; Haseman, J.K.; Sills, R.C. 2000a. Magnetic fields and mammary cancer in rodents: A critical review and evaluation of published literature. Radiation Research, 153(5), Part 2: 617.

Boorman, G.A.; Rafferty, C.N.; Ward, J.M.; Sills, R.C. 2000b. Leukemia and lymphoma incidence in rodents exposed to low-frequency magnetic fields. Radiation Research, 153(5), Part 2: 627.

Bracken, M.B.; Belanger, K.; Hellenbrand, K.; Dlugosz, L.; Holford, T.R.; McSharry, J.E.; Addesso, K.; Leaderer, B. 1995. Exposure to electromagnetic fields during pregnancy with emphasis on electrically heated beds: association with birth weight and intrauterine growth retardation. Epidemiology, 6(3): 263-270.

Burchard, J.F.; Nguyen, D.H.; Block, E. 1998. Effects of electric and magnetic fields on nocturnal melatonin concentrations in dairy cows. J Dairy Sci. 81(3):722-7.

Erren, T.C. 2001. A meta-analysis of epidemiological studies of electric magnetic fields and breast cancer in women and men. Bioelectromagnetics Supplement, 5: S105-S119.

Fernie, K.J.; and Bird, D.M. 1999. Effects of electromagnetic fields on body mass and food-intake of American kestrels. The Condor. 101:616-621.

Fernie, K.J.; Bird, D.M.; Dawson, R.D.; Lague, P.C. 2000. Effects of electromagnetic fields on the reproductive success of American kestrels. Physiol Biochem Zool. 73(1):60-5.

Gammon, M.D.; Schoenberg, J.B.; Britton, J.A.; Kelsey, J.L.; Stanford, J.L.; Malone, K.E.; Coates, R.J.; Brogan, D.J.; Potischman, N.; Swanson, C.A.; Brinton, L.A. 1998. Electric blanket use and breast cancer risk among younger women. American Journal of Epidemiology, 148: 556-63.

Goodwin Jr., J.G. 1975. Big game movement near a 500-kV transmission line in northern Idaho. Bonneville Power Administration, Engineering and Construction Division, Portland, OR, June 27.

Green, L.M.; Miller, A.B.; Villeneuve, P.J.; Agnew, D.A.; Greenberg, M.L.; Li, J.H.; Donnelly, K.E. 1999a. A case control study of childhood leukemia in southern Ontario, Canada, and exposure to magnetic fields in residences. International Journal of Cancer, 82:161-170.

Green, L.M.; Miller, A.B.; Agnew, D.A.; Greenberg, M.L.; Li, J.H.; Villeneuve, P.J.; Tibshirani, R. 1999b. Childhood leukemia and personal monitoring of residential exposures to electric and magnetic fields in Ontario, Canada. Cancer Causes and Control, 10: 233-243.

Greenberg, B.; Bindokas, V.P.; Frazier, M.J.; Gauger, J.R. 1981. Response of honey bees, *apis mellifera L.*, to high-voltage transmission lines. Environmental Entomology, 10: 600-610.

Greenland, S.; Sheppard, A.; Kelsh, M.; Kuane, W.; Poole, C.; Kelsh, M.A. 2000. Childhood leukemia and power frequency magnetic fields: analysis from pooled data of thirteen epidemiologic studies. Epidemiology, 11: 624-634.

HCN (Health Council of the Netherlands). 2000. Report on Exposure to Electromagnetic Fields (0 Hz – 10 MHz). No. 2000/06E.

Hefeneider, S.H.; McCoy, S.L.; Hausman, F.A.; Christensen, H.L.; Takahashi, D.; Perrin, N.; Bracken, T.D.; Shin, K.Y.; Hall, A.S. 2001. Long-term effects of 60-Hz electric vs. magnetic fields on IL-1 and IL-2 activity in sheep. Bioelectromagnetics, 22(3):170-177.

Holmberg, B. 1995. Magnetic fields and cancer: animal and cellular evidence—an overview. Environ Health Perspect. 103 Suppl 2:63-7.

Huuskonen, H.; Saastamoinen, V.; Komulainen, H.; Laitinen, J.; Juutilainen, J. 2001. Effects of low-frequency magnetic fields on implantation in rats. Reprod Toxicol, 15(1):49-59.

IEE (Institution of Electrical Engineers), Biological Effects Working Party. May 2000. The possible harmful biological effects of low level electromagnetic fields of frequencies up to 300 GHz. IEE Position Statement.

Kirschvink, J.L.; and Gould, J.L. 1981. Biogenic magnetite as a basis for magnetic field detection in animals. Biosystems, 13(3):181-201.

Kirschvink, J.L.; Diaz Ricci, J.; Nesson, M.H.; Kirschvink, S.J. 1992. Magnetite-based magnetoreceptors in animals: structural, behavioral, and biophysical studies. Electric Power Research Institute (EPRI), Report No. TR-102008, Palo Alto, CA. September.

Kroeker, G.; Parkinson, D.; Vriend, J.; Peeling, J. 1996. Neurochemical effects of static magnetic field exposure. Surg Neurol, 45(1):62-6.

Laden, F.; Neas, L.M.; Tolbert, P.E.; Holmes, M.D.; Hankinson, S.E.; Spiegelman, D.; Speizer, F.E.; Hunter, D.J. 2000. Electric blanket use and breast cancer in the nurses' health study. American Journal of Epidemiology, 152(1): 41-49.

Langholz, B. 2001. Factors that explain the power line configuration wiring code - childhood leukemia association: what would they look like? Bioelectromagnetics Supplements, 5: S19-S31.

Larkin, R.P., and Sutherland, P.J. 1977. Migrating birds respond to Project Seafarer's electromagnetic field. Science, 195(4280): 777-9 1977, Feb 25.

Lee, G.M.; Neutra, R.R.; Hristova, L.; Yost, M.; Hiatt, R.A. 2000. The use of electric bed heaters and the risk of clinically recognized spontaneous abortion. Epidemiology, 11: 406-415.

Lee, J., Stormshak, F., Thompson, J., Thinesen, P., Painter, L., Olenchek, B., Hess, D., Forbes, R. 1993. Melatonin secretion and puberty in female lambs exposed to environmental electric and magnetic fields. Biol Reprod 49(4):857-64

Lee, J.M. BPA Biological Studies Task Team. 1996. Electrical and biological effects of transmission lines: a review. Bonneville Power Administration, Portland, Oregon, December.

Lee, J.M., Stormshak, F., Thompson, J., Hess,D.L., Foster, D.L. 1995. Melatonin and puberty in female lambs exposed to EMF: a replicate study. Bioelectromagnetics, 16(2):119-23

Linet, M.S.; Hatch E.H.; Kleinerman, R.A.; Robinson, L.L.; Kaune, W.T.; Friedman, D.R.; Seversch, R.K.; Haines, C.M.; Hartsock, C.T.; Niwa, S.; Wacholder, S.; Tarone, R.E. 1997. Residential exposure to magnetic fields and acute lymphoblastic leukemia in children. New England Journal of Medicine, 337: 1-7.

Loberg, L.I.; Engdahl, W.R.; Gauger, J.R.; McCormick, D.L. 2000. Expression of cancer-related genes in human cells exposed to 60 Hz magnetic fields. Radiation Research, 153(5): 679-684.

McBride, M.L.; and Gallagher, RP; Theriault, G; Armstrong, BG; Tamaro, S; Spinelli, JJ; Deadman, JE; Fincham, S; Robinson, D; Choi, W. 1999. Power-frequency electric and magnetic fields and risk of childhood leukemia in Canada. American Journal of Epidemiology, 149:831-842.

McCormick, D.L.; Boorman, G.A.; Findlay, J.C.; Hailey, J.R.; Johnson, T.R.; Gauger, J.R.; Pletcher, J.M.; Sill, R.C.; Haseman, J.K. 1999. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F mice. Toxicologic Pathology, 27:279-285.

Neutra, R.R., and Del Pizzo, V. 2001. A richer conceptualization of "exposure" for epidemiological studies of the "EMF mixture". Bioelectromagnetics Supplements, 5: S48-S57.

NIEHS (National Institute of Environmental Health Sciences). 1998. Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields: Working Group Report. NIH Publication No. 98-3981. Research Triangle Park, NC: National Institute of Environmental Health Sciences of the U.S. National Institutes of Health.

NIEHS (National Institute of Environmental Health). 1999. Health effects from exposure to power line frequency electric and magnetic fields. NIH; National Institute of Health; NIH No. 99-4493; Research Triangle Park, NC.

NRC (National Research Council). 1997. An evaluation of the U.S. Navy's extremely low frequency communications system ecological monitoring program. National Academy Press, Washington, D.C.

NRPB (National Radiological Protection Board). 2001. Response statement of the NRPB: ELF electromagnetic fields and the risk of cancer. National Radiological Protection Board, Chilton, Dicot, Oxon, Volume 12, No.1, ISNB 0-859951-456-0.

Picton, H.D., Canfield, J.E., Nelson, G.P. 1985. The impact of a 500-kV transmission line upon the North Boulder Winter Elk Range. US Forest Service Contract 53-0398-30E-3.

Raaschou-Nielsen, O.; Hertel, O.; Thomsen, B.L.; Olsen, J.H. 2001. Air pollution from traffic at the residence of children with cancer. American Journal of Epidemiology, 153(5): 433-43.

Radiation Research. 2000. (Special Edition Updating RAPID results.) 153(5): 637-641. *See entries under Balcer-Kubiczek, Boorman, Loberg, and Ryan.*

Reynolds, P.; Elkin, E.; Scalf, R.; Von Behren, J.; Neutra, R.R. 2001. A case-control pilot study of traffic exposures and early childhood leukemia using a geographic information system. Bioelectromagnetics Supplements, 5:S58-S6.

Rogers, L.E., Beedlow, P.A., Carlile, D.W., Ganok, K.A., Lee, J.M. 1984. Environmental studies of a 1100-kV prototype transmission line: an annual report for the 1984 study period. Prepared by Battelle Pacific Northwest Laboratories for Bonneville Power Administration, Portland, Oregon.

Ryan, B.M.; Symanski, R.R.; Pomeranz, L.E.; Johnson, T.R.; Gauger, J.R.; McCormick, D.L. 1999. Multi-generation reproduction toxicity assessment of 60-Hz magnetic fields using a continuous breeding protocol in rats. Teratology, 59(3): 156-62.

Ryan, B.M.; Polen, M.; Gauger, J.R.; Mallett, E.; Kerns, M.B.; Bryan, T.L.; McCormick, D.L. 2000. Evaluation of the developmental toxicity in Sprague-Dawley rats. Radiation Research, 153(5): 637-641.

Savitz, D.A., Wachtel, H., Barnes, F.A., John, E.M. & Tvrdik, J.G. 1988. Case-control study of childhood cancer and exposure to 60 Hz magnetic fields. American Journal of Epidemiology, 128**,** 21-38.

Schuz, J.; Grigat, J.P.; Brinkmann, K.; Michaelis, J. 2001. Residential magnetic fields as a risk factor for childhood acute leukaemia: results from a German population-based case-control study. International Journal of Cancer, 91(5): 728-735. January 2.

Southern, W.E. 1975. Orientation of gull chicks exposed to project Sanguine's electromagnetic field. Science, 189: 143-144.

Stormshak, F., Bracken, T.D., Carey, M., Chartier, V., Dickson, L., Forbes, R., Hall, A., Havens, P., Hess, D., Krippaehne, S., Lee, J., Ogden, B., Olenchek, B., Painter, L., Rowe, K., Stearns, R., Thinesen, P., Thompson, J. 1992. Joint HVAC transmission EMF environmental study: final report on experiment 1. Bonneville Power Administration, Contract # DE-B179-90BPO4293, Portland, OR, May.

Thompson, J.M.; Stormshak, F.; Lee, J.M.; Hess, D.; Painter, L. 1995. Cortisol secretion and growth in ewe lambs chronically exposed to electric and magnetic fields of a 60-Hertz 500-kilovolt AC transmission line. J Animal Sci, 73(11):3274-80

UKCCS (United Kingdom Childhood Cancer Study Investigators). 1999. Exposure to power frequency magnetic fields and the risk of childhood cancer. The Lancet, 353(9194): 1925-31.

UKCCS (United Kingdom Childhood Cancer Study Investigators). 2000. Childhood cancer and residential proximity to power lines. British Journal of Cancer, 83:1573-80.

Vollrath, L.; Spessert, R.; Kratzsch, T.; Keiner, M.; Hollmann H. 1997. No short-term effects of high-frequency electromagnetic fields on the mammalian pineal gland. Bioelectromagnetics, 18(5):376-87.

Walcott, C.; Gould, J.L.; Lednor, A.J. 1988. Homing of magnetized and demagnetized pigeons. J Exp Biol, 134:27-41.

Walker, C.E.; Seitelman, D.L.; McElhaney, J.H.; Mullen, S.P.; Hagadorn, B.; Seto, Y.J. 1982. Effects of high-intensity 60-Hz fields on bone growth. Journal of Bioelectricity, 1(3):339-349.

Wartenberg, D. 2001a. The potential impact of bias in studies of residential exposure to magnetic fields and childhood leukemia. Bioelectromagnetics Supplements, 5: S32-S47.

Wartenberg, D. 2001b. Residential EMF exposure and childhood leukemia: Meta-analysis and population attributable risk. Bioelectromagnetics Supplements, 5: S86-S104.

Wilson, B.W.; Anderson, L.E.; Hilton, D.I.; Phillips, RD. 1981. Chronic exposure to 60-Hz electric fields: effects on pineal function in the rat. Bioelectromagnetics, 2(4):371-80.

Wrensch, M.; Yost, M.; Miike, R.; Lee, G.; Touchstone, J. 1999. Adult glioma in relation to residential power frequency electromagnetic field exposures in the San Francisco Bay Area. Epidemiology, 10: 523-527.

Zaffanella, L.E. 1993. Survey of residential magnetic field sources. Vol. 1: Goals, results, and conclusions. (EPRI TR-102759-V1, Project 3335-02). Electric Power Research Institute, Palo Alto, CA.

Zheng, T.Z.; Holford, T.R.; Mayne, S.T.; Owens, P.H.; Zhang, B.; Boyle, P.; Carter, D.; Ward, Y.W.; Zahm, S.H. 2000. Exposure to electromagnetic fields from use of electric blankets and other in-home electrical appliances and breast cancer risk. American Journal of Epidemiology, 151(11): 1103-11.

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